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Impact of Irminger Rings on Deep Convection in the Labrador Sea: Mooring Instrument, Cruise CTD, and APEX Data Report September 2007 – September 2009

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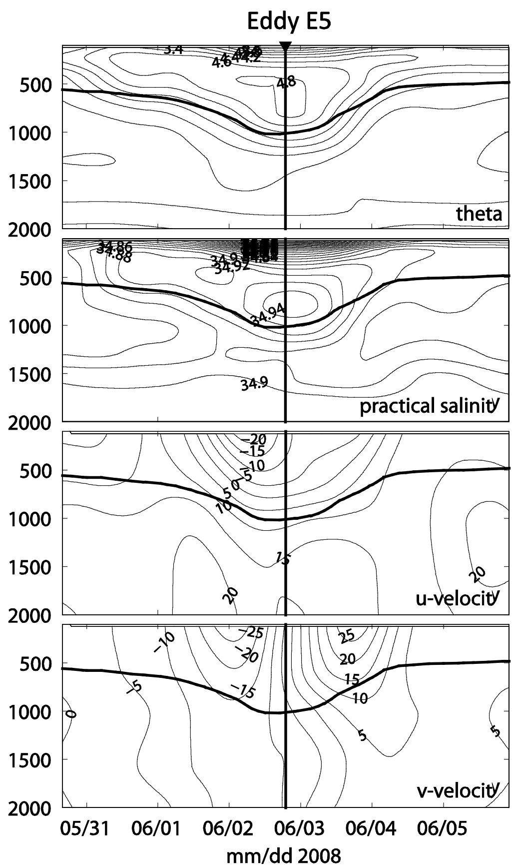

Technical Report

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Grant OCE-0623192.

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Impact of Irminger Rings on Deep Convection in the Labrador Sea: Mooring Instrument, CTD, and APEX Data Report September 2007 - September 2009

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Approved for Distribution:

John M. Toole, Chair

Department of Physical Oceanography

Abstract

This is the final data report of all hydrographic station, mooring, and subsurface float data collected by the Woods Hole Oceanographic Institution in 2007-2009 during the *Impact of Irminger Rings on Deep Convection in the Labrador Sea* experiment (IRINGS). The objectives of IRINGS were to (1) to determine the full water column hydrographic and velocity structure of newly-formed Irminger Rings that have entered the interior Labrador Sea; (2) to observe how Irminger Ring core properties are modified by atmospheric forcing over their lifetime; and (3) to improve the interpretation of sea surface height (SSH) anomalies in terms of newly formed coherent heat containing Irminger Rings. The mooring deployment and recovery cruises were both on the *R/V* Knorr: KN192-01 in September 2007 and KN196-01 in September 2009, respectively.

The single mooring held eight Aanderaa current meters (RCM-11), two Submerged Autonomous Launch Platforms (SALPs), and nine Seabird microcats (SBE37), deployed from 26 September 2007 through 27 September 2009, yeilding full water column (100-3000 meters) records of temperature, salinity, pressure, and velocity data for the two year period. The two SALP cages contained eleven APEX floats, and released some of these floats according to local oceanographic conditions, so as to seed the floats in passing Irminger Rings, and the remainder of floats as timed releases. Thirteen conductivity-temperature-depth (CTD) stations were taken on the mooring recovery cruise, creating a boundary current cross-section from the mooring site to Nuuk, Greenland.

Front Cover Figure Caption:

One example of an Irminger Ring found in the mooring record (June 2008). From top to bottom: theta, practical salinity, u-velocity, and v-velocity. The center of the eddy (bold vertical black line) is calculated as the point of maximum (downward) displacement of the 27.7 σ_0 isopycnal (bold black line). The thin vertical lines 24 hours before and after eddy center mark the approximate eddy core in time. Adapted from Furey et al. (2013).

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1. Introduction

Large, coherent, long-lived anticyclonic eddies are shed from a localized formation site off west Greenland into the Labrador Sea interior (e.g., Hátún et al., 2007; Lilly *et al.*, 2003). These Irminger Rings (IRs) are thought to transport an isolated core of anomalous water predominantly along a narrow corridor toward the south (Lilly *et al.*, 2003). Data and modeling studies indicate that these rings are important contributors to the heat and freshwater budgets of the Labrador Sea (Lazier, 1980; Lazier *et al.*, 2002; Pickart *et al.*, 2002; Lilly *et al.*, 2003; Straneo, 2005; Spall, 2004; Katsman et al., 2004; Hátún et al., 2007; Rykova et al., 2009; Gelderloos et al. 2011; De Jong et al., submitted), but considerable uncertainty remains because previous observations have been mainly limited to older, weaker eddies and those that had not yet left the boundary.

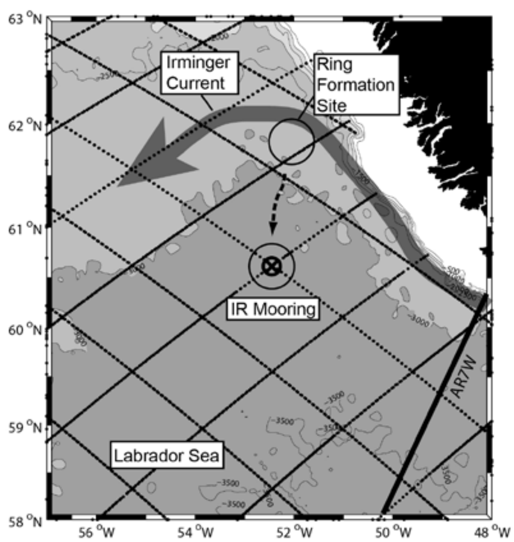

Figure 1. Chart showing the location of the IRINGS mooring, super-imposed on bathymetry (500 m contour interval) and Jason altimeter ground tracks. Outer circle represents ring with 20-km core radius.

The goal of the *Impact of Irminger Rings on Deep Convection in the Labrador Sea* experiment (IRINGS) was to advance our understanding of the impact of IRs on deep convection and restratification by collecting new information on their initial structure and life history. The specific objectives were: (1) to determine the full water column hydrographic and velocity structure of newly-formed IRs that have entered the interior Labrador Sea, (2) to observe how IR core properties are modified by atmospheric forcing over their lifetime, and (3) to improve the interpretation of sea surface height anomalies in terms of newly formed coherent heat containing IRs.

To achieve these objectives, we deployed one densely instrumented, two-year mooring in the northeastern Labrador Sea in the path of newly formed IRs (Figure 1). As well as current meter, temperature and salinity instrumentation, the mooring held two Submerged Autonomous Launch Platforms (SALPs; Fratantoni, 2010). The SALPs contained eleven APEX profiling floats, some of which were released singly or in pairs each time an eddy core passed by the mooring, and the remainder at pre-programmed timed intervals. The APEX floats parked and drifted at 300 meters depth, and profiled from the surface to 1000 meters at five-day intervals. Thirteen conductivity-temperature-depth (CTD) stations were taken on the mooring recovery cruise, creating a boundary current cross-section from the mooring site to Nuuk, Greenland, the final port. The geographical locations and timeline of these measurements are depicted in Figure 2.

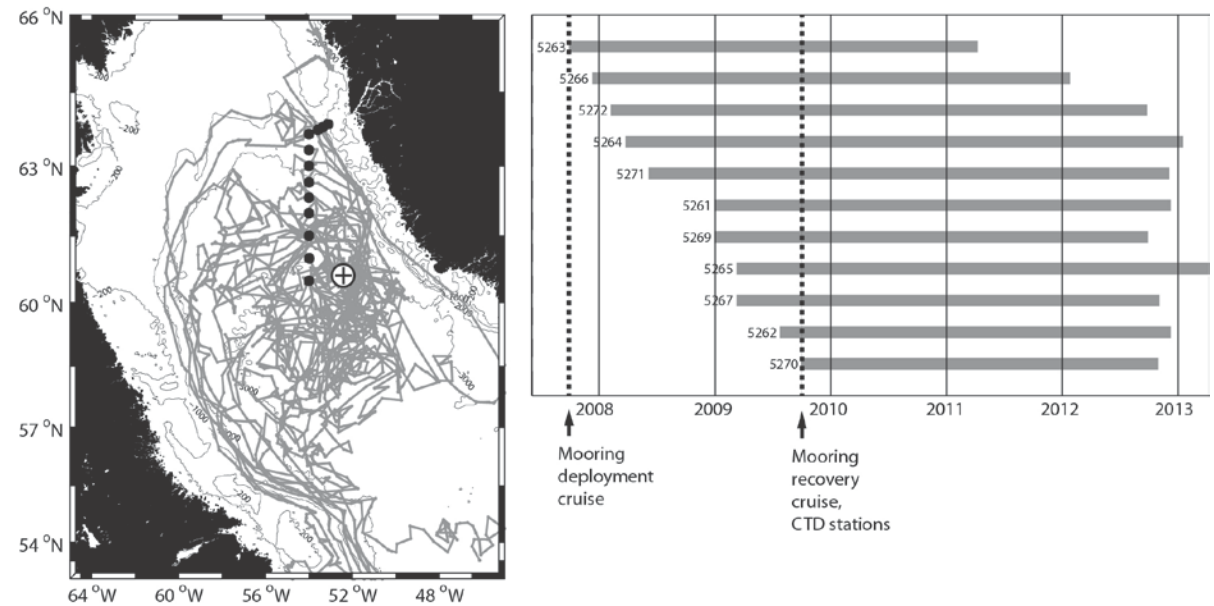

Figure 2. (left) Chart showing mooring location (circle-x), CTD locations (at black dots and at circle-x), and APEX trajectories (gray lines) from start of experiment in September 2007 through the present, in the Labrador Sea. (APEX travelled outside of this basin, see Appendix F.) Bathymetry is labeled in meters. (right) Duration chart showing timing of deployment and recovery cruises, CTD stations, and APEX first through final transmissions.

2. Mooring setup and instrument performance

The mooring included an array of eight Aanderaa RCM-11 current meter instruments and nine Seabird SBE-37 microcats from 100 – 3000 meters depth, and two SALP cages at ~500 m with their own pressure and temperature recording devices. The mooring was deployed from 25 September 2007 through 28 September 2009. All instruments returned 100% of expected data , except for one current meter at 250 m which failed early, so that no data were recovered for this instrument. The SALP cages contained six bays each, and were loaded with profiling APEX floats. The SALP controller released APEX floats from the cage bays using criteria based on real-time pressure and temperature measurements recorded by the instrument. The approximate depth of the SALPs were chosen to target the vertical position where the eddy would exhibit the highest temperatures associated with the IRs (front cover figure). The mooring was designed to be less stiff than a traditional mooring by using less flotation. This was done to enhance dips in pressure caused by the passage of eddies, so that this information could be utilized by the SALP controller to identify when the SALP cage was in an eddy. Table 1 lists the mooring instrument types, serial numbers and properties measured, Figure 3 shows a mooring schematic and Figure A1 shows the mooring diagram. Current meter, MicroCAT, and SALP instrument mean, maximum, minimum, and standard deviation are listed in Table A1. A summary of instrument accuracy and resolution may be found in Table A2. A review of the SALP mechanics and the SALP controller algorithm may be found in Furey et al. (2013).

Table 1. Mooring layout with nominal instrument depths and properties. The observed parameters are eastward velocity (u), northward velocity (v), temperature (T), conductivity (C), and pressure (P).

Depth (m)	Instrument Type #s/n	Properties / Notes
100	RCM11 #147	u, v, T
101	SBE37 #5291	P, C, T
200	SBE37 #2043	C, T
250	RCM11 #345	Instrument failed.
400	SBE37 #2029	C, T
500	RCM11 #160	u, v, T
511	SALP master	P, T
518	SALP slave	P, T
750	SBE37 #5290	P, C, T
1000	RCM11 #128	u, v, T
1001	SBE37 #1649	C, T
1250	SBE37 #1644	C, T
1500	RCM11 #162	u, v, T
1501	SBE37 #2037	C, T
1750	SBE37 #1637	C, T
2000	RCM11 #374	u, v, T
2001	SBE37 #2030	C, T
2500	RCM11 #159	u, v, T
3000	RCM11 #156	u, v, T

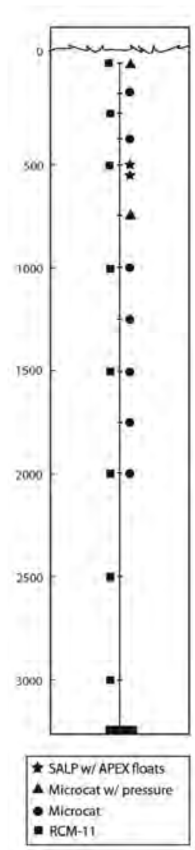

Figure 3. Mooring schematic.

3. Mooring instrument quality control and calibration

All instrument data were truncated to in-water time periods, from 26 September 2007 00:00 to 28 September 2009 00:00. The initial and final instrument clock offsets were applied as linear offsets to each mooring instrument. Initial clock offsets were all assumed to be 0, as we had no information to the contrary. Current meter final clock offsets were provided in a spreadsheet by Scott Worrilow (WHOI); microcat final clock offsets were recorded in the ship's log sheets by John Lund (WHOI). The SALP instruments had no retrieval log sheets, and therefore initial and final clock offsets were assumed to be zero. Final clock offsets were recorded on deck at recovery, and may be found in Table A4.

All mooring pressure data (SALP, current meter, and pressure-recording microcat) were de-trended as follows: Because the mooring was designed to have large pressure excursions during high-speed current events (blow downs), and because there were more blow-down events in the latter half of the mooring record, a simple de-trend algorithm was biased by the latter blow downs. Therefore, the large pressure excursions were isolated and removed from the data before calculating the trend by removing any pressure data more than ± 5 dbars of the mean pressure. The trend of the pressure data for the two years was found with the remaining data, and removed linearly from the entire pressure record. We were careful to choose a pressure window (in the case ± 5 dbars) that did not affect the calculation of the actual trend. As a test, we also calculated $\delta P/\delta T$ for two time periods far apart in the mooring record that were recorded during quiescent times, and calculated a linear trend in pressure between those two time periods. This procedure yielded similar results as the method above. Both the original and de-trended pressure records were saved in the MATLAB structure for each instrument (Tables A7-A9).

Quality control and calibration procedures specific to instrument sensor type are detailed below. After all quality control and calibration described in Sections 3.1 through 3.3, the mooring data were low-passed filtered to remove tides using a 40-hour Butterworth filter. The original data were sampled as follows: SALP: hourly, microcats: 15-minute; current meters: 30-minute intervals. The data were resampled in time to a uniform hourly time step. The data at the original sampling rates are available in each instrument's structure file (Tables A7-A9).

3.1 Submerged Autonomous Lagrangian Profilers (SALPs) T/P Modules

No further processing was done on the temperature and pressure records from the SALPs after the clock correction and pressure de-trending described above, as there were no obviously erroneous spikes. The thermistor had been calibrated before the instrument was deployed. A complete review of the SALP performance may be found in Furey et al. (2013). SALP temperature and pressure data plots may be found in Appendix B.

3.2 Aanderaa Current Meters (RCM11s)

After the clock correction and pressure de-trending described above, these instruments were processed as follows: Geomagnetic corrections were applied linearly over time using routines written by D. Torres (WHOI), and the most recent International Geomagnetic Reference Field (IGRF11) data set. Speed data were modified by a scale factor of the ratio in-situ sound velocity/standard sound velocity (where standard sound velocity is 1500 m/sec), as recommended by AADI. Hogg and Frye (2007) suggest scaling all RCM11 speed data by a factor of 1.1. This correction was not applied based on information provided by D. Torres (WHOI) and Ivan Victoria (AADI). Both felt that since the Hogg and Frye study was based on a single instrument, the Hogg and Frye results were not necessarily applicable to all RCM instruments.

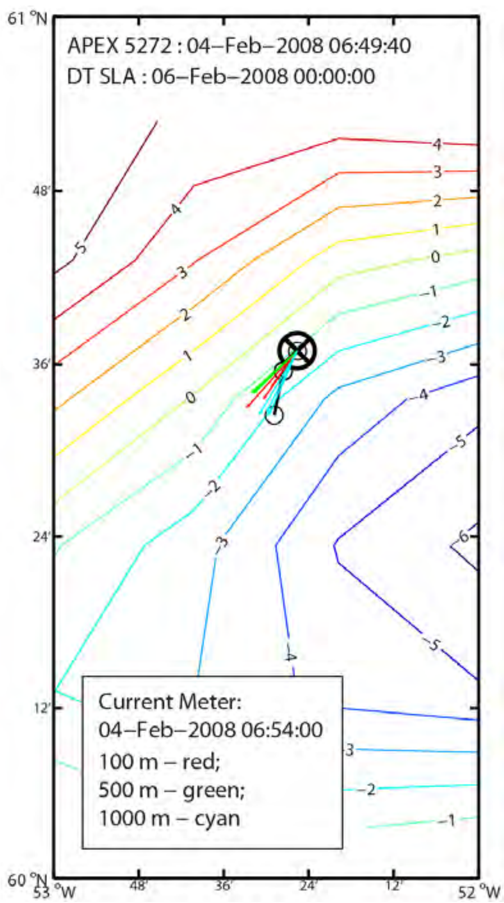

Figure 4. Qualitative check of velocity direction measured by the current meters using APEX float positions. Mooring site is drawn as a bold circle-x. APEX first and second surface positions are plotted as circles connected by a black line. Current meter velocity vectors are plotted at the closest available time to the first APEX position. After release, the APEX dropped from 500 to about 1600 meters depth and then surfaced to get a position fix. Therefore, the velocity vector from the float represents a depth-averaged value. AVISO merged sea level anomaly (MSLA) data for the nearest date to the float release are contoured every 1 centimeter. MSLA data rarely agreed with the current meter or APEX displacement vectors, both because of smoothing of the MSLA data in space and time, and because SLA can only be used to estimate the surface geostrophic velocity anomaly.

The current meter velocities were qualitatively checked against the independent information provided by the APEX floats immediately after release, using the mooring position and first APEX position, recorded within six hours of the float release, to construct a velocity vector that could be used to qualitatively assess the current meter information. One example of this comparison is shown in Figure 4. The current meter velocities generally agreed with the APEX displacement vectors near the times of APEX releases throughout the two year course of the mooring record. Temperature data required no editing or correction; the data were free of spikes and the thermistors had been calibrated before the instrument was deployed. A synthetic pressure record was constructed for each RCM-11 according to the method described in Section 3.3 and included in the final structure data for each current meter. Individual current meter data plots may be found in Appendix C.

3.3 Sea-Bird MicroCATs (SBE37s)

After the clock correction and pressure de-trending described above, these instruments were processed as follows: The temperature data required no editing, as there were no obviously erroneous spikes.

Synthetic pressure records were constructed for all instruments without pressure sensors. Pressures were recorded by the microcats at ~100 and 750 m depth as well as by the SALPs at ~500 m. Predicted profiles of mooring blow down for several velocity profiles were supplied by the mooring's designer (George Tupper, WHOI). The predicted blow down matched the blow down recorded by the instruments at 100, 500 and 750 m depth. Therefore, this blow down profile was used to construct pressure records for the instruments that lacked a pressure sensor. In fact, the blow down profile of the mooring is such that the upper 500 m of cable remains nearly vertical even during maximum blow down (Figure 5). Thus, the synthesized pressure records of the instruments in the upper 500 m of the water column contain very little error.

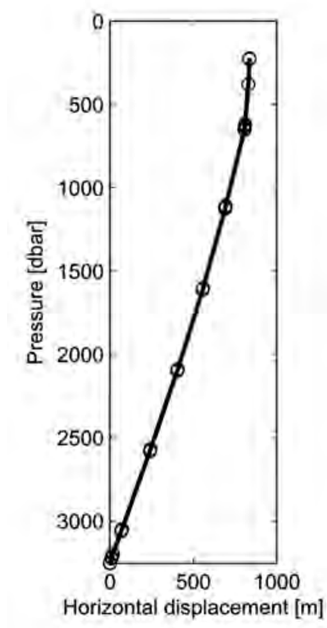

Figure 5. Modeled mooring blow down at a current speed of 75 cm/s at the surface decreasing to 0 cm/s at the bottom. This mooring profile was used for the reconstruction of pressure time series.

The conductivity measured by the microcats without pressure sensors assumes a constant reference pressure when converting frequency counts to conductivity. Seabird considers this a negligible error under normal circumstances (minimal pressure variability), but in this case, the large excursions of the mooring (up to 800 meters) meant that this was no longer negligible and needed to be corrected. This was done as advised by Carol Janzen (SeaBird, Inc.) by modifying the conductivity data, not by recalculating conductivity from the frequency data. We computed a time dependent multiplier using recorded temperature (T) and the synthetic pressure data (P) and δ and ε calibration coefficients specific to each instrument and provided by SeaBird, Inc. as follows:

$C_P = [\ (10+ 10* \delta *T)/(10+ 10* \delta *T + 10* \varepsilon *P)\ ] * C_O$;

where C_P is the pressure corrected conductivity, Co is the conductivity output by the instrument. Co is calculated using a preset reference pressure set before deployment, in these instruments 0 dbars. We used the pressure-corrected conductivity, along with the synthetic pressure, to calculate salinity according to the Gibbs Seawater Toolbox 2010 MATLAB routine '`gsw_SP_from_C.m`'. The difference between using corrected and uncorrected conductivity in salinity space (S calculated with C corrected minus S calculated using C uncorrected) ranged from 0.001 – 0.003 practical salinity units at 200 meters depth. The larger values occurred when the mooring was blown to deeper pressures. Although the offset when the mooring is upright can be corrected by using an appropriate reference pressure, blowdown does cause variability in the conductivity (in addition to the variability in salinity calculated from conductivity and synthetic pressure) that results in salinity differences up to 0.002.

The conductivity time series contained some obviously bad data that needed to be removed (instruments s/ns 1637 2029 2037 2043) and replaced with NaNs, or adjusted (s/n 2037), the gross adjustments are detailed in Table A3. Once these adjustments were made, all conductivity data were processed to remove outliers using a 12-hour (49-point) window with a 2.0 standard deviation cut-off, done twice. (This is similar to the procedure done by R. Curry for HydroBase, http://www.whoi.edu/hydrobase/.)

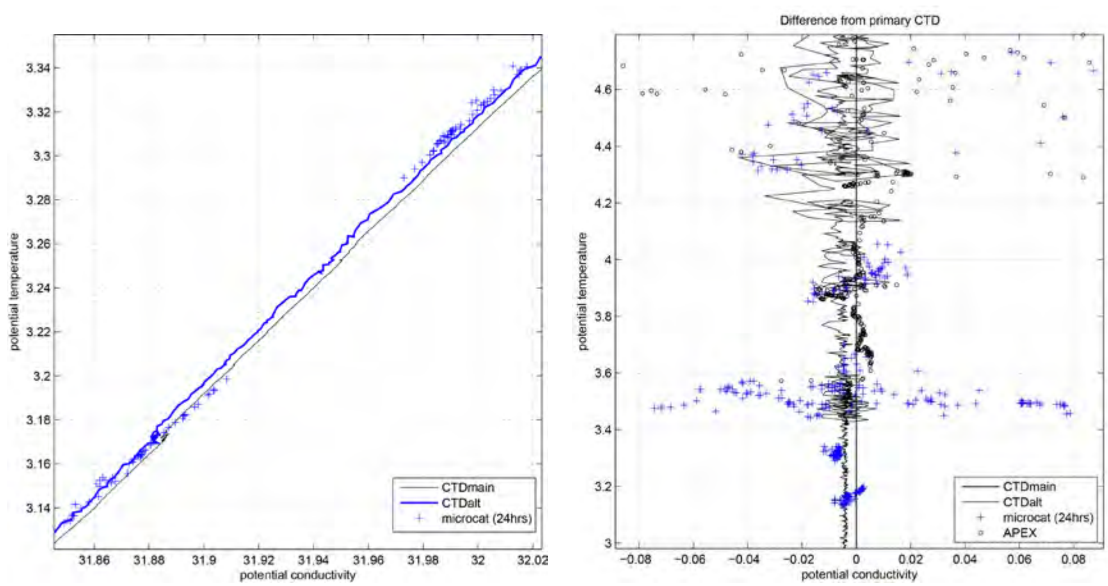

Figure 6. (left) Deep CTD conductivity (primary (main) and secondary (alt) probes) for the CTD taken at the mooring site when the mooring was recovered and microcat conductivity for the final 24 points versus T. The secondary probe is noisy, but the microcat conductivity agrees better with these data than that of the primary probe. (right) Difference between microcat, secondary CTD, and nearby APEX potential conductivity from the primary CTD conductivity probe, plotted in T-C space.

Finally, the conductivity data were calibrated using the post-recovery Seabird calibration coefficients. The final microcat conductivity was *not* adjusted to the recovery CTD conductivity values (see Figure 6). The CTD conductivity values were suspect – the CTD contained two conductivity probes, and the probe values were offset from each other. The secondary probe, though noisier than the primary, had deep values that generally matched the deep microcat conductivity data. Therefore, we did not adjust the microcat records to the primary CTD values at this site. Further investigation revealed that the primary CTD conductivity sensor was replaced after this research cruise, for unknown reasons. We considered calibrating the microcat conductivity data using the historical deep CTD conductivity in this region (as suggested by J. Toole), but the available data were too sparse to perform this operation.

The final agreement ('fit') between temperature (RCM11s, SALP, SBE37s) and conductivity (SBE37s) data and the CTD cast performed at mooring recovery are near or within the manufacturer stated instrument accuracy (CTD accuracy + mooring instrument accuracy; Table A2) for the deep values (below 1000 m), and some shallow values. Individual microcat data plots may be found in Appendix D.

3.4 Data gridding

The recorded data were interpolated vertically in order to get full profiles of temperature, salinity and velocity. A shape preserving spline function was used to grid the data to 25 dbar intervals. At every time step this spline fitting was applied to the temperature and salinity at the depths of the microcats. Because of the non-monotonic vertical profiles of temperature and salinity in the Labrador Sea, a control on the fitting was needed. This was especially true for salinity, which has a local minimum at mid-depth associated with Labrador Sea Water. As a control, density profiles were derived both from the newly fitted 25 dbar interval profiles of temperature and salinity as well as by spline fitting the density observations at the original instrument depths (which is necessarily monotonic because of the inherently stable water column). The spline shape parameters were then adjusted to get the best match between the two density profiles. The same spline fitting function was also applied to the u and v velocity measurements.

4. APEX Float quality control and calibration

The twelve APEX floats deployed during this experiment were built and ballasted at Teledyne Webb Research. The APEX were programmed to park at 300 dbars, profiling 0-1000 meters once every 5 days. An issue with float ballasting put the floats initially deeper than planned (near 600-800 meters). Adjustment to the programmed park depth (~300 dbar) took on average 2.75 days (Table A5). Two SALP cages were mounted on the mooring, with six bays per cage, and loaded with 11 APEX floats. The SALP released APEX based on ambient oceanographic conditions that signaled a passing Irminger Ring. One float (#5263) was deployed off the ship before mooring deployment. Ten floats were successfully deployed from the cages, and one float was stuck in the cage. This stuck float (#5270) was launched off the ship during the recovery cruise. Eleven APEX successfully completed their missions, one float, #5268, stopped transmitting after a single cycle for unknown reasons. Three APEX were affected by defective Druck pressure sensors and had Negative Pressure Drift, but not of the Truncated variety. This meant that the pressure drift could be corrected as outlined in Barker et al. (2011). The park point of APEX # 5263 was adjusted while in mission to try to redirect the float from its northward trajectory towards the shallow Davis Strait back into deeper water. This was unsuccessful, and the float got stuck in shallow water on the continental shelf west of Greenland for most of its mission. Further review of APEX performance may be found in Furey et al. (2013). A summary of APEX release type, positions, and dates may be found in Table A5.

APEX quality control and calibration were done according to the procedures used on WHOI ARGO data as follows. The profile data were visually inspected to identify and flag bad points. This process included visual comparison to nearby historical data and a check for density inversions (see Appendix F for historical data positions used in this procedure). Next, we applied a thermal-mass correction to the conductivity data based on the Johnson et al. (2007) analysis of the SeaBird 41CP. Finally, the long-term stability of the conductivity sensor was examined using the Owens and Wong (2009) method, which compares the conductivity measured by the float with nearby historical data objectively-mapped to the location of the float observations. Comparison was made with both climatology of historical CTD casts and climatology of high-quality Argo profiles. Adjustments were only made to the reported conductivity if there was clear evidence from the historical comparisons of a drift or offset greater than 0.01 PSU. Only one of the floats (4901945) had a detectable trend in conductivity calibration with the float measuring too salty by up to 0.04 PSU. All data may be found at the Argo GDACs: http://www.usgodae.org/argo/argo.html or ftp://ftp.ifremer.fr/ifremer/argo/. APEX identification numbers, URLS, and quality control and calibration notes for individual floats may be found in Table A6. A composite APEX 'spaghetti' diagram and individual float plots may be found in Appendix F.

5. Conductivity-Temperature-Depth Station quality control and calibration

The CTD data were obtained as ancillary data for the project. CTD station locations may be found in Figure 2. CTD data were processed by Jane Dunworth, WHOI, according to standard practices of the Physical Oceanography Department. No bottle data were taken on the cruise, so the salinity data were not corrected against in-situ water samples. The primary conductivity sensor on the CTD was replaced after the cruise for unknown reasons. There was an offset between the primary and secondary conductivity sensors which makes the data suspect (also see Section 3.3). Plots of the individual CTD casts may be found in Appendix E.

6. Acknowledgements

The authors would like to thank David Fratantoni for generously allowing us to build upon his prototype SALP design. We would also like to thank Fiamma Straneo, Mike Spall, Jonathan Lilly, George Tupper and Dana Swift for help with instruments, processing software, and mooring design and deployment related to this experiment. The authors wish to thank WHOI engineer Rick Trask for mooring design, and Will Ostrom, John Lund, and the crews of the R/V Knorr for expert mooring deployment and recovery. This work was funded by the National Science Foundation Grant OCE-0623192.

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Appendix A: Mooring diagram (Figure A1), instrument measurement simple statistics (Table A1), instrument metadata tables (Tables A2-A6) and mooring data structure format (Tables A7-A9).

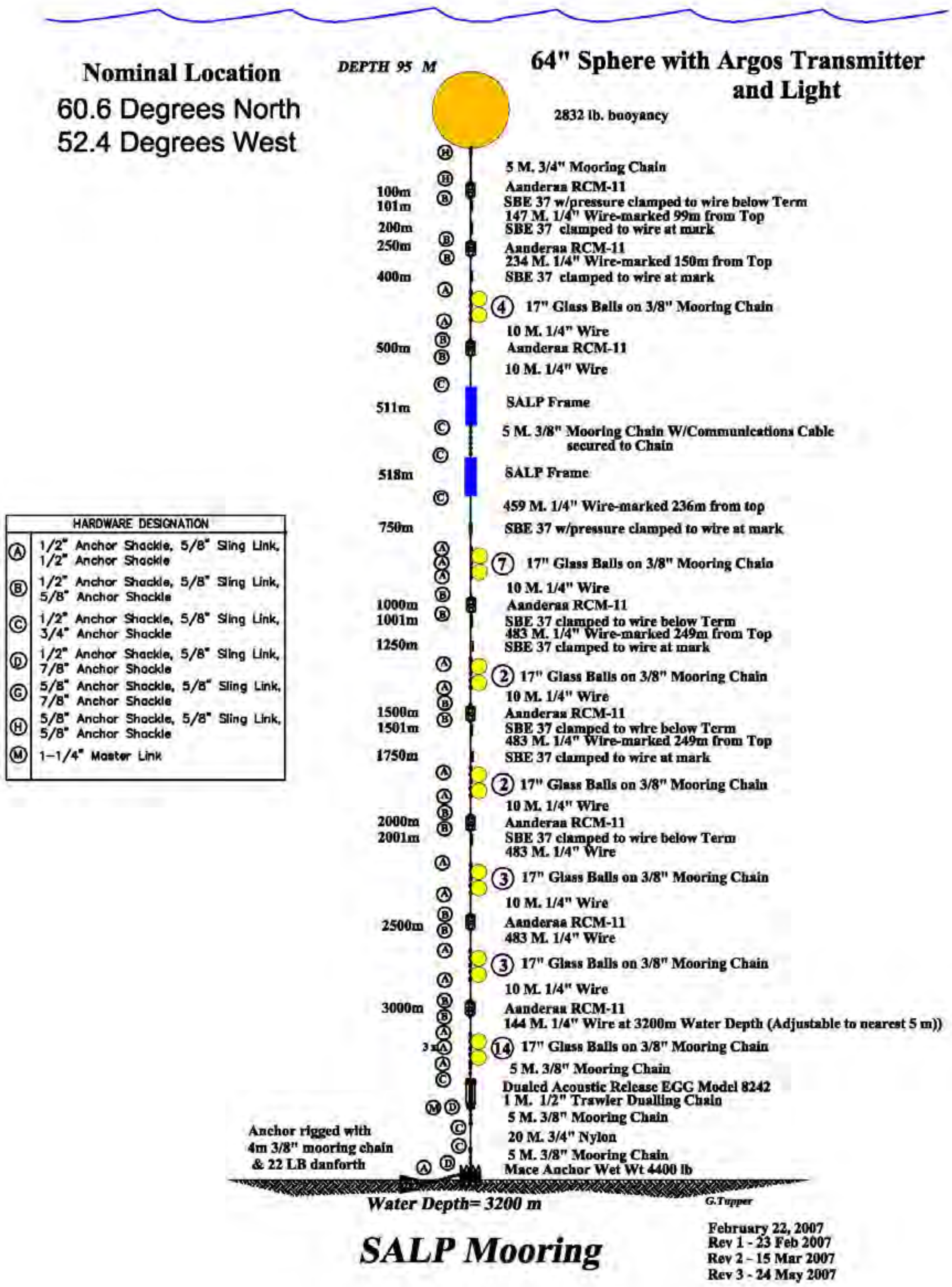

Figure A1. Mooring diagram drawn by George Tupper, WHOI.

Table A1. Instrument property simple statistics.

Property	Instrument Type #s/n	Depth (m)	Mean	Maximum	Minimum	Standard Deviation
P	SBE37 #5291	101	141	734	118	46
	SALP master	511	553	1139	530	46
	SALP slave	518	561	1146	538	46
	SBE37 #5290	750	806	1372	784	45
T	RCM11 #147	100	4.60	7.02	1.52	0.85
	SBE37 #5291	101	4.634	7.083	1.475	0.847
	SBE37 #2043	200	4.723	6.443	2.741	0.569
	SBE37 #2029	400	4.391	5.904	3.305	0.417
	RCM11 #160	500	4.20	5.64	3.24	0.38
	SALP master	511	4.18	5.58	3.36	0.37
	SALP slave	518	4.18	5.56	3.38	0.37
	SBE37 #5290	750	3.855	4.973	3.298	0.275
	RCM11 #128	1000	3.63	4.54	3.35	0.17
	SBE37 #1649	1001	3.650	4.554	3.372	0.167
	SBE37 #1644	1250	3.591	4.186	3.318	0.102
	RCM11 #162	1500	3.60	3.86	3.14	0.06
	SBE37 #2037	1501	3.601	3.870	3.139	0.057
	SBE37 #1637	1750	3.430	3.768	2.993	0.077
	RCM11 #374	2000	3.22	3.59	2.82	0.07
	SBE37 #2030	2001	3.2281	3.591	2.818	0.068
	RCM11 #159	2500	2.84	3.10	2.44	0.06
	RCM11 #156	3000	2.19	2.67	1.71	0.10
S	SBE37 #5291	101	34.828	35.254	34.151	0.116
	SBE37 #2043	200	34.906	35.093	34.617	0.057
	SBE37 #2029	400	34.908	35.031	34.713	0.039
	SBE37 #5290	750	34.828	35.254	34.151	0.116
	SBE37 #1649	1001	34.865	34.976	34.799	0.021
	SBE37 #1644	1250	34.876	34.945	34.808	0.019
	SBE37 #2037	1501	34.899	34.931	34.836	0.012
	SBE37 #1637	1750	34.904	34.925	34.877	0.005
	SBE37 #2030	2001	34.902	34.922	34.878	0.005

Table A1. Instrument property simple statistics, continued.

Property	Instrument Type #s/n	Depth (m)	Mean	Maximum	Minimum	Standard Deviation
u	RCM11 #147	100	2.1	76.4	-59.3	15.5
	RCM11 #160	500	2.8	65.6	-50.9	12.9
	RCM11 #128	1000	3.3	53.4	-43.1	11.8
	RCM11 #162	1500	3.2	43.7	-37.4	11.8
	RCM11 #374	2000	2.0	45.0	-33.4	10.1
	RCM11 #159	2500	1.1	46.0	-35.3	9.8
	RCM11 #156	3000	-0.5	29.3	-40.4	9.7
v	RCM11 #147	100	0.0	65.6	-67.0	16.2
	RCM11 #160	500	0.0	50.5	-52.5	13.0
	RCM11 #128	1000	0.6	50.7	-45.9	11.9
	RCM11 #162	1500	0.6	45.5	-43.1	11.2
	RCM11 #374	2000	1.4	40.4	-40.3	10.0
	RCM11 #159	2500	2.3	38.8	-38.8	9.5
	RCM11 #156	3000	3.7	45.8	-43.7	9.4

Table A2. Instrument accuracy and resolution.

Instrument	Component	Initial accuracy	Typical drift	Resolution
Seabird MicroCAT SBE 37-SM*	conductivity	±0.0003 S/m (±0.003 mS/cm)	±0.0003 S/m (±0.003 mS/cm) per month	0.00001 S/m (0.0001 mS/cm)
	temperature	±0.002°C	±0.0002°C per month	0.0001°C
	Pressure (Druck)	0.1% of full scale range	0.05% of full scale range per year	0.002% of full scale range
Current Meter Aanderaa RCM-11**	speed	±0.15 cm/s	Not specified.	0.3 cm/s
	direction	±5° for 0-15° tilt and ±7.5° for 15-35° tilt.	Not specified.	0.35°
	Temperature (Fenwall GB32JM19)	±0.05°C	Not specified.	0.1% of full scale range Note: All RCM11s used the Low Range (–2.70 to 21.77°C) for temperature conversion, so resolution for this mooring is 0.02°C.
SALP*** (Designed and built at WHOI by J. Valdes)	Temperature YSI (YSI 55008)	Not specified.	<0.01°C/10 months	Not specified.
	Pressure Druck (PDCR 900-4210) Pressure transducer	0.1% of full scale range	0.05% of full scale range per year	0.002% of full scale range

*http://www.seabird.com/products/spec_sheets/37smdata.htm @ 20 December 2011
**http://www.icm.csic.es/bio/projects/eflubio/RCM11.pdf @ 20 December 2011
***http://datasheet.octopart.com/44011RC-Measurement-Specialties-datasheet-8450905.pdf @ 11 march 2013

Table A3. Microcat conductivity corrections.

Instrument s/n	Conductivity sections adjusted by mean on either side	Conductivity sections cut
mc1637	None.	02-Dec-2008 06:16:49 to 02-Dec-2008 06:46:48; 15-Feb-2009 05:32:07 to 15-Feb-2009 11:17:07
mc2029	None.	28-Mar-2009 09:17:01 to 28-Mar-2009 20:47:03
mc2037	None.	06-Feb-2008 15:45:09 to 06-Feb-2008 19:15:09
mc2043	10-Jul-2008 03:46:13 to 12-Jul-2008 20:46:13; 12-Jul-2008 23:46:13 to 14-Jul-2008 14:46:15; 14-Jul-2008 16:16:15 to 16-Jul-2008 00:01:14; 16-Jul-2008 06:46:14 to 25-Jul-2008 01:46:16; 25-Jul-2008 01:46:16 to 26-Jul-2008 18:16:18	05-Jul-2008 07:46:11 to 08-Jul-2008 03:31:12; 10-Jul-2008 20:46:12 to 10-Jul-2008 23:46:12; 12-Jul-2008 13:01:13 to 12-Jul-2008 16:01:13; 14-Jul-2008 00:16:14 to 14-Jul-2008 06:31:15; 24-Jul-2008 17:46:16 to 24-Jul-2008 18:46:16

Table A4. Instrument clock drifts.

Nominal Depth (m)	Instrument Type #s/n	Final Clock Offset (mm:ss. + means instr. clock fast)
100	RCM11 #147	-11:55
101	SBE37 #5291	+02:45
200	SBE37 #2043	+03:05
250	RCM11 #345	Instrument leaked.
400	SBE37 #2029	+02:42
500	RCM11 #160	+06:20
511	SALP master	Unknown, assumed 00:00
518	SALP slave	Unknown, assumed 00:00
750	SBE37 #5290	+04:10
1000	RCM11 #128	+09:04
1001	SBE37 #1649	+02:26
1250	SBE37 #1644	+04:40
1500	RCM11 #162	+14:00
1501	SBE37 #2037	+00:52
1750	SBE37 #1637	+03:01
2000	RCM11 #374	+04:50
2001	SBE37 #2030	+04:20
2500	RCM11 #159	+18:45
3000	RCM11 #156	+14:00

Table A5. APEX deployments or releases listed in order of launch.

Float ID/cage	Release Date/ Final Transmission Date/ No. Profiles Completed	Release type	Days to adjust to park point	Notes.
Deployment Cruise.				
5263/slave	2007-09-26 / 2011-04-11/ 246	Released from ship prior to arrival at mooring site.	2.33	Initial park point of 300 meters. This float moved northward into shallow waters of Davis Straits, and the park point was reset to ~550, then 100, then 250 meters depth, in an unsuccessful attempt to keep the float in the central Labrador Sea.
Begin SALP Underwater Mission.				
5266/master	2007-12-08 / 2012-01-27 / 295	T-P criteria	2.46	-
5272/master	2008-02-04 / 2012-09-26 / 331	T-P criteria	2.70	-
5264/slave	2008-03-23 / 2013-01-18 / 344	Timed	2.62	-
5271/master	2008-06-03 / 2012-12-06 / 321	T-only criteria	2.63	Negative pressure drift (NPD) from leaking Druck pressure sensor.
Release criteria changed to allow for independent launch.				
5261/slave	2008-12-28 / 2012-12-10 / 282	T-P criteria	2.82	-
5269/master	2008-12-28 / 2012-09-30 / 270	T-P criteria	3.70	Bad salinity; NPD from leaking Druck pressure sensor.
5265/master	2009-03-07 / 2013-02-18 / 281	T-P criteria	2.94	-
5267/slave	2009-03-06 / 2012-11-04 / 261	T-P criteria	2.50	-
5268/slave	2009-09-27/ 2009-09-27 / 0	Timed	-	Died after first transmission.
5262/slave	2009-07-22 / 2012-12-10 / 242	Timed	3.08	-
Recovery Cruise.				
5270/master	2009-09-28 / 2012-11-01 / 223	Launched from ship at mooring site.	2.46	NPD from leaking Druck pressure sensor.

Table A6. APEX Identification numbers for DACs, WHOI URLs, notes.

APEX s/n	Trans. ID #	IMEI	WMO#	AOML#	WHOI URL
5261	3473	300224010810200	4901401	4470	http://argo.whoi.edu/wmo/4901401.html
	Notes:	NPD pressure adjustment applied to profile 269 and higher.			
5262	3474	300224010817330	4901402	4471	http://argo.whoi.edu/wmo/4901402.html
	Notes:	NPD pressure adjustment applied to profile 228 and higher. Float spent about 100 cycles in water less than 400m deep but returned to deep water and showed no sign of conductivity drift.			
5263	3475	300224010816200	4901403	4472	http://argo.whoi.edu/wmo/4901403.html
	Notes:	Drifted onto the shelf at cycle 19 and didn't come off. Not possible for deep comparison to calibrate conductivity sensor. Data looks OK but without reference, flagged the last year of salts as 2: 'probably good'.			
5264	3476	300224010814200	4901404	4473	http://argo.whoi.edu/wmo/4901404.html
	Notes:	NPD pressure adjustment applied to profile 322 and higher. Four winters of beautiful deep mixed layers. Towards end of the record float gets carried by DWBC around Cape Farewell: cycles 330-338.			
5265	3477	300224010813220	4901405	4474	http://argo.whoi.edu/wmo/4901405.html
	Notes:	NPD pressure adjustment applied to profile 253 and higher.			
5266	3478	300224010818200	4901406	4475	http://argo.whoi.edu/wmo/4901406.html
	Notes:	Drifted onto the shelf after profile 85 and didn't come off.			
5267	3479	300224010812200	4901407	4476	http://argo.whoi.edu/wmo/4901407.html
	Notes:	NPD pressure adjustment applied to profile 254 and higher.			
5269	3481	300224010815330	4901449	4477	http://argo.whoi.edu/wmo/4901449.html
	Notes:	No salvageable conductivity measurements. Temperature appears OK up until profile 189.			
5270	3482	300224010813200	4901445	4478	http://argo.whoi.edu/wmo/4901445.html
	Notes:	Only float to receive a conductivity calibration correction. Float drifts salty with linear trend over time. CTD sensor goes bad after profile #145.			
5271	3483	300224010815200	4901446	4479	http://argo.whoi.edu/wmo/4901446.html
	Notes:	NPD pressure adjustment applied to profile 308 and higher.			
5272	3484	300224010810210	4901447	4480	http://argo.whoi.edu/wmo/4901447.html
	Notes:	NPD pressure adjustment applied to profile 331 and higher.			

Table A7. RCM MATLAB data structure, using #156 as example.

```
>> rcm

    setup: RCM setup
 datenums: Matlab datenum
     date: Date (year,mon,day,hr,min,sec)
   rawspd: Speed before corrections applied.
   rawdir: Direction before corrections applied.
   magvar: Magnetic variation (corrected)
      spd: speed (cm/s, corrected for in situ sound speed)
      dir: direction (deg T North, corrected for mag. Var.)
    u_vel: East component of velocity
    v_vel: North component of velocity
     temp: Temperature (deg C)
 u_vel_lp: East comp. of velocity, after low pass filter applied
    v_vel_lp: East comp. of velocity, after low pass filter
applied
     temp_lp: temperature, after low pass filter applied
  datenums_h: datenums, gridded to hourly interval
   u_vel_lph: u_vel_lp, gridded to hourly interval
   v_vel_lph: v_vel_lp, gridded to hourly interval
    temp_lph: temp_lp, gridded to hourly interval

>> rcm.setup

          cruiseID: 'IR'
         mooringID: 'A' % there was only one mooring.
        instrument: 'RCM-11 s/n 156'
          latitude: 60.6163
         longitude: -52.4223
            bottom: 3217
         instdepth: 3000
     in_water_time: '26-September-2007'
    out_water_time: '27-September-2009'
 init_clock_offset: '00:00' (‘MM:SS’)
final_clock_offset: '+14:00' (‘MM:SS’)
             SSfac: 1.0060 (scale factor: …
 sw_svel(35,mean(in situ temp),depth)./1500)
       lp_per_hrs: low-pass filter window (hours)
         processor: 'H. Furey, WHOI'
    processed_date: '07-Oct-2011 07:44:17'
```

Table A8. Microcat MATLAB data structure, using #2037 as example.

```
>> mc

           setup: Microcat setup
        datenums: Matlab datenum
            date: Date (year,mon,day,hr,min,sec)
      pres_drift: pressure drift calculated using 'detrend.m'*
         rawtemp: temperature before processing
         rawpres: pressure before processing*
          rawsal: salinity before processing
         editsal: salinity after large sections cut
             sal: salinity after outliers cut using std filter,
                and large sections edited by hand (ginput.m)
            temp: same as rawtemp
            pres: pressure after trend removed*
         pres_lp: low-pass filtered detrended pressure*
         temp_lp: low-pass filtered temperature
          sal_lp: edited, cleaned, low-pass filtered salinity
      datenums_h: datenums, gridded to hourly interval
        pres_lph: pres_lp, gridded to hourly interval*
        temp_lph: temp_lp, gridded to hourly interval
         sal_lph: sal_lp, gridded to hourly interval
>> mc.setup

            cruiseID: 'IR'
           mooringID: 'A'
          instrument: 'SBE37 s/n 2037'
            latitude: 60.6163
           longitude: -52.4223
              bottom: 3217
           instdepth: 1501
       in_water_time: '26-September-2007'
      out_water_time: '27-September-2009'
   init_clock_offset: '00:00' ('MM:SS')
  final_clock_offset: '+00:52' ('MM:SS')
    stddevmultiplier: standard deviation multiplier
           winlength: length of outlier filter
          lp_per_hrs: low-pass filter window (hours)
           processor: 'H. Furey, WHOI'
      processed_date: '07-Oct-2011 11:32:58'

* Pressure data only exist for microcats with pressure
sensors, s/n 5290 and 5291.
```

Table A9. SALP MATLAB data structure, using master as example.

```
>> salp

          setup: SALP setup
       datenums: Matlab datenum
           date: Date (year,mon,day,hr,min,sec)
        rawpres: pressure before processing
     pres_drift: pressure drift calculated using ‘detrend.m’
           pres: pressure after trend removed
           temp: same as raw temperature
     controller: release type
         TPcrit: code for criteria of meeting T/P requirements
        pres_lp: low-pass detrended pressure
        temp_lp: low-pass temp
     datenums_h: datenums, gridded to hourly interval
       pres_lph: pres_lp, gridded to hourly interval
       temp_lph: temp_lp, gridded to hourly interval

>> salp.setup

           cruiseID: 'IR'
          mooringID: 'A'
         instrument: 'SALP s/n master'
           latitude: 60.6163
          longitude: -52.4223
             bottom: 3217
          instdepth: 511
      in_water_time: '26-September-2007'
     out_water_time: '27-September-2009'
  init_clock_offset: '00:00' (‘MM:SS’)
 final_clock_offset: '00:00' (‘MM:SS’)
         lp_per_hrs: low-pass filter window (hours)
          processor: 'H. Furey, WHOI'
     processed_date: '12-Oct-2011 13:18:58'
```

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Appendix B: SALP pressure and temperature records.

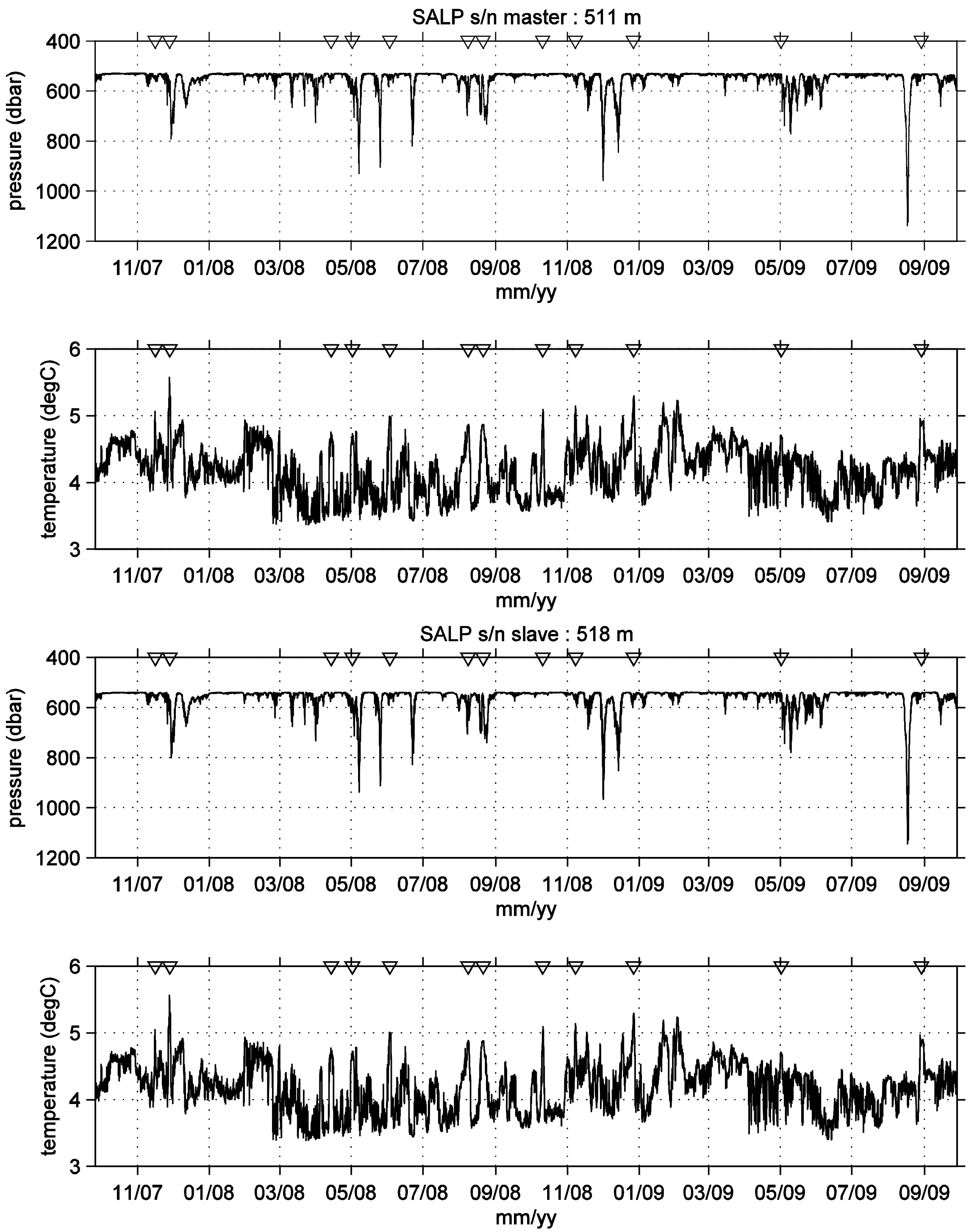

Figure B1. SALP Master (top two panels) and slave (bottom two panels) pressure and in situ temperature records. Triangles designate positions in time of the 12 best anticyclones, see De Jong at al. (submitted) for details.

Appendix C: Aanderaa RCM11 current meter synthetic pressure (see Section 3.3), in situ temperature, u-velocity and v-velocity records. On all plots, triangles designate positions in time of the 12 best anticyclones in the mooring record, see De Jong at al. (submitted) for details. The current meter positioned at 250 meters leaked, and no data were recovered.

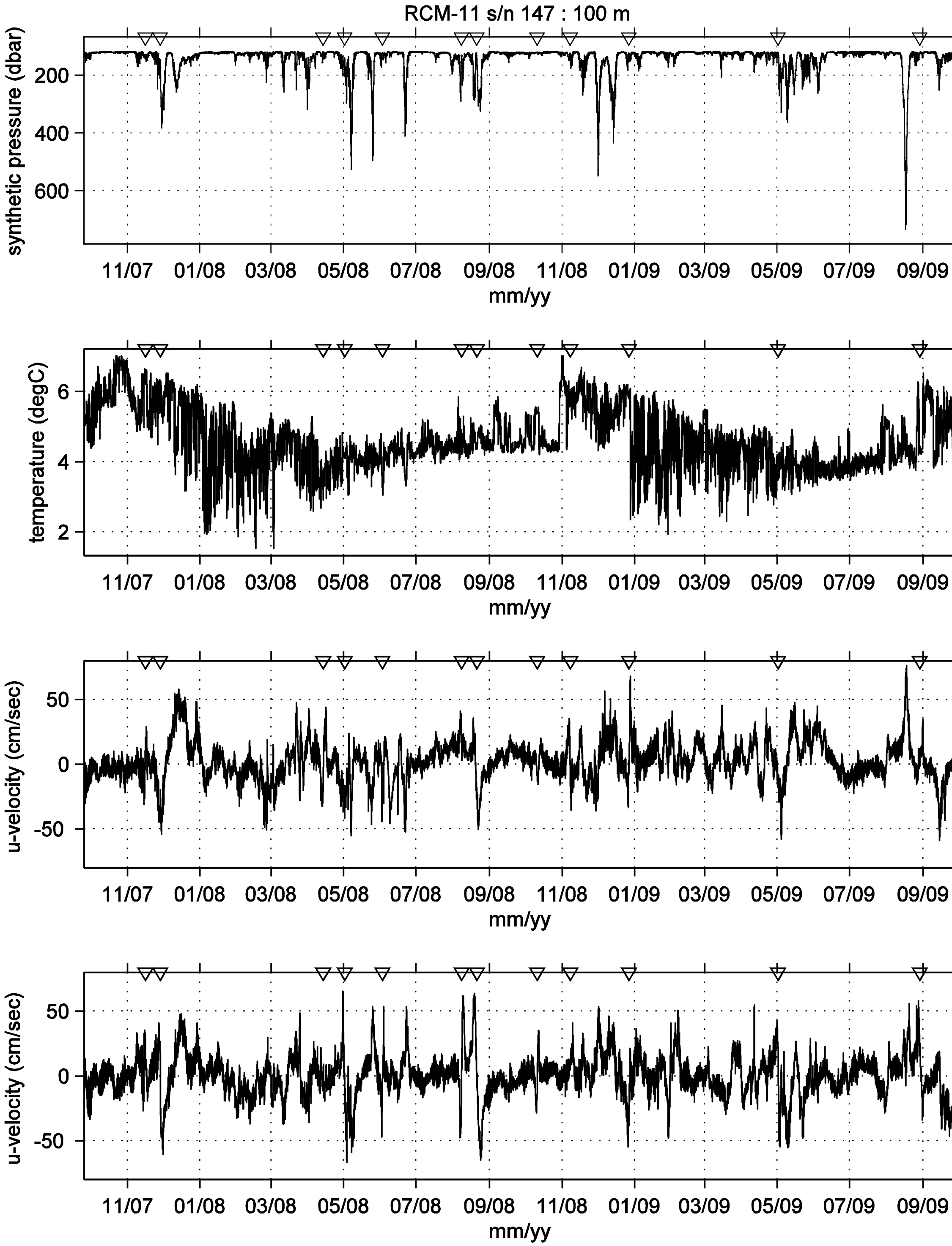

Figure C1. Current meter #147, positioned at 100 meters.

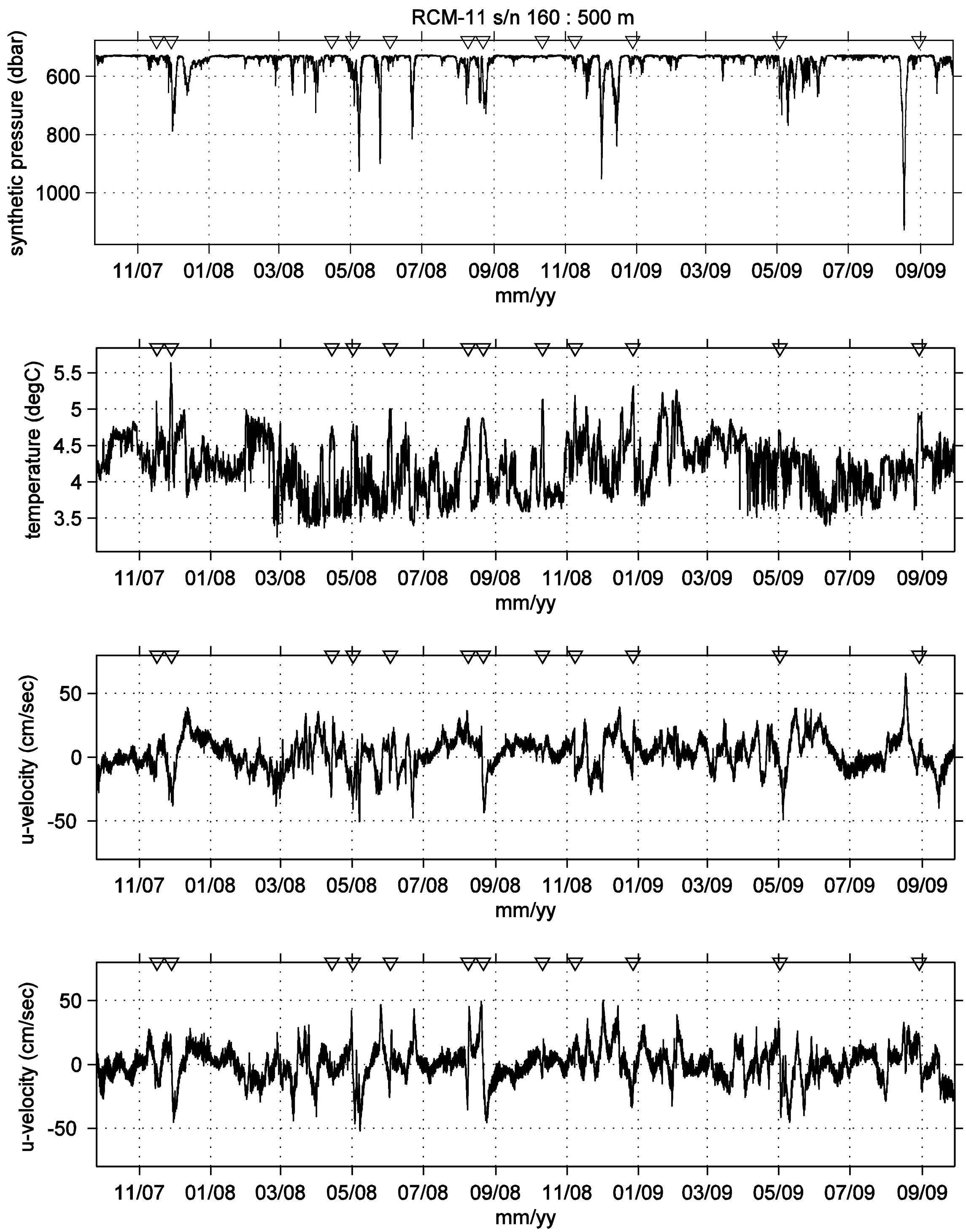

Figure C2. Current meter #160, positioned at 500 meters.

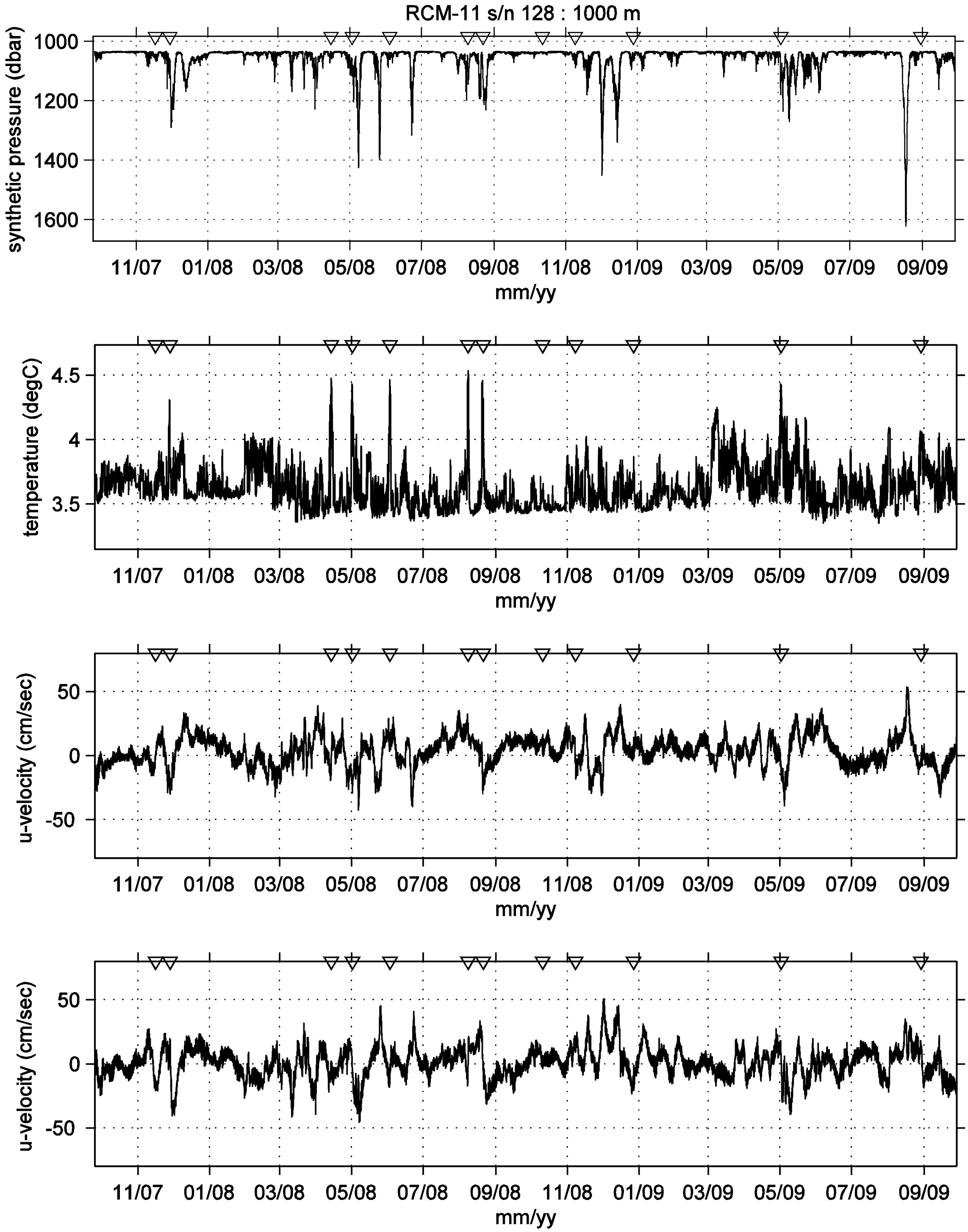

Figure C3. Current meter #128, positioned at 1000 meters.

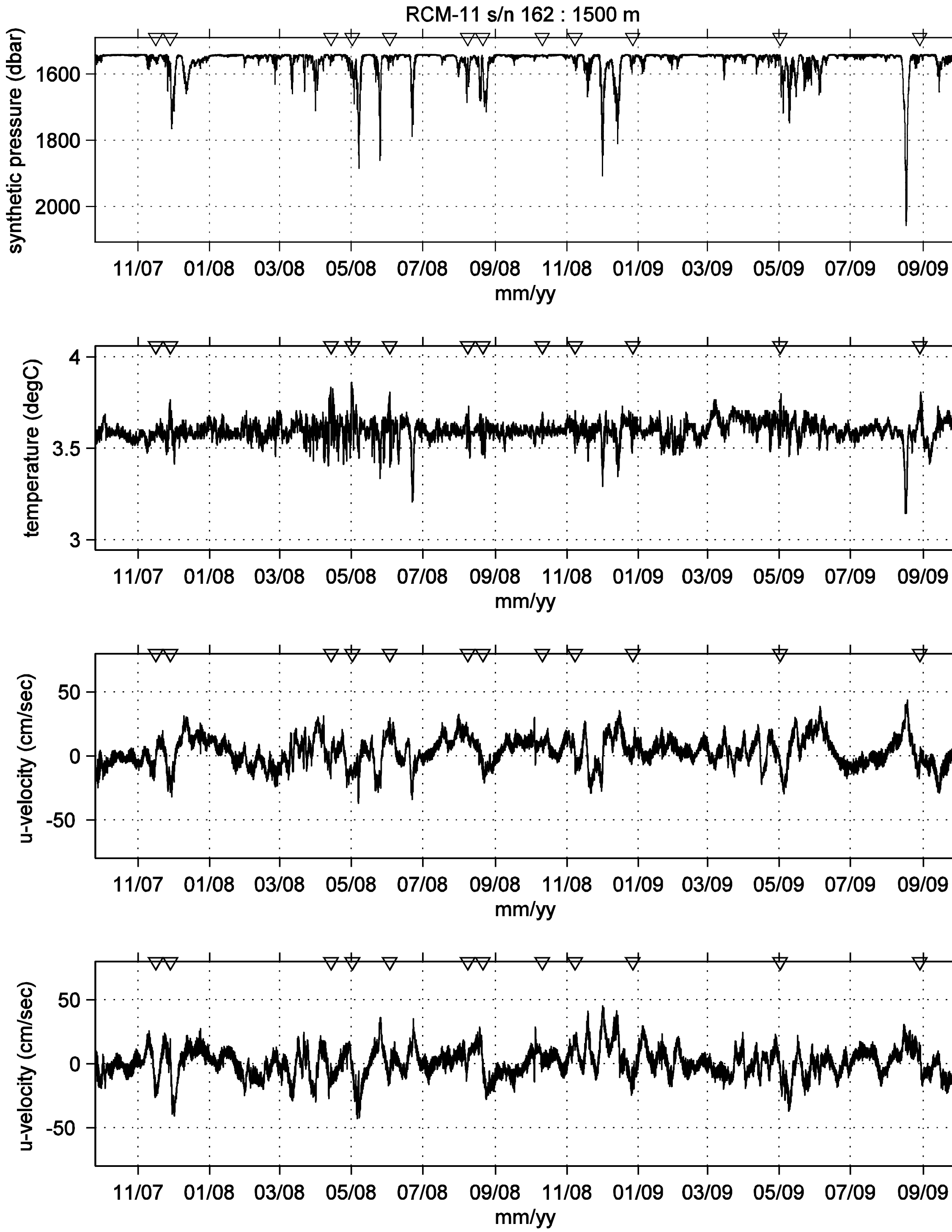

Figure C4. Current meter #162, positioned at 1500 meters.

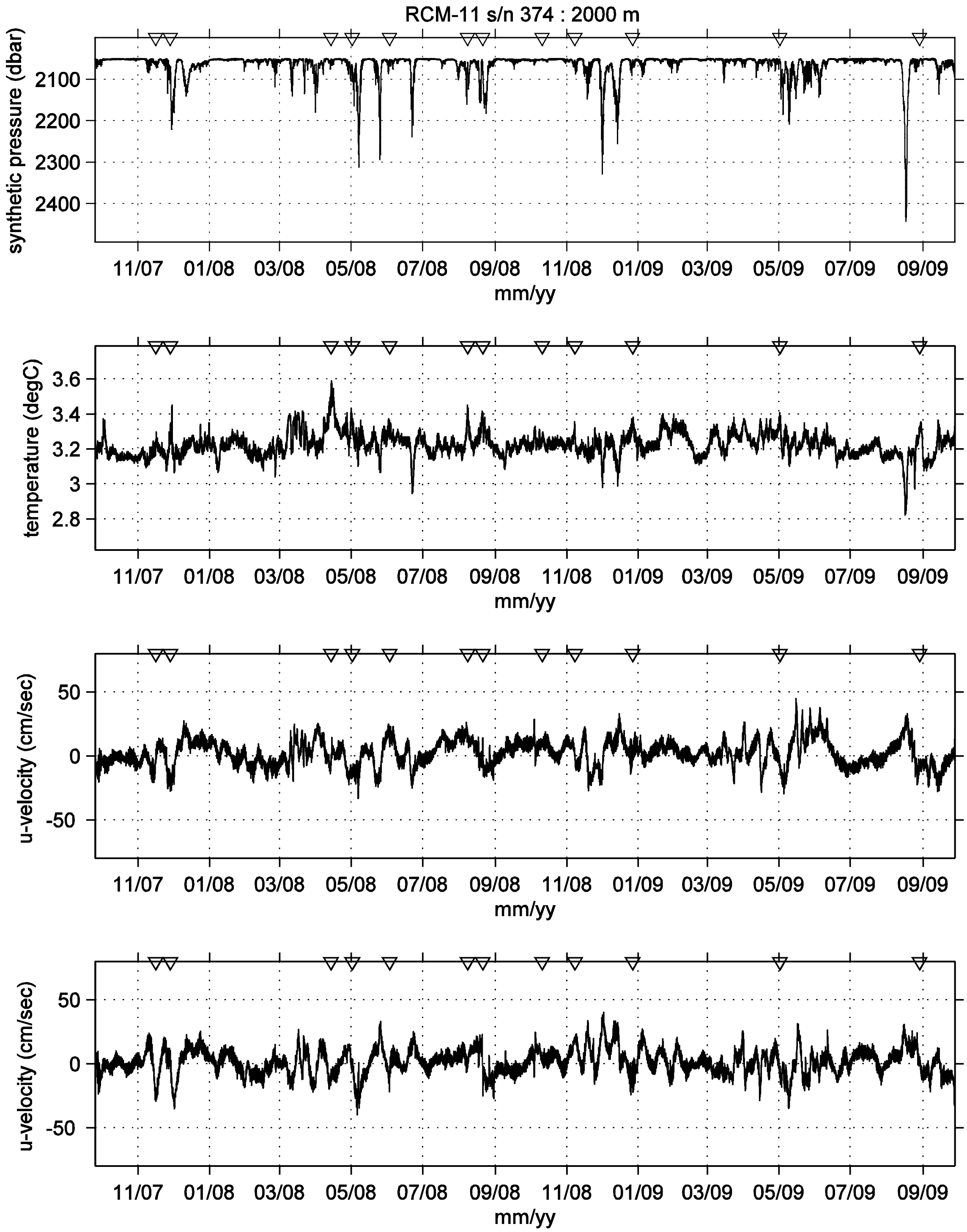

Figure C5. Current meter #374, positioned at 2000 meters.

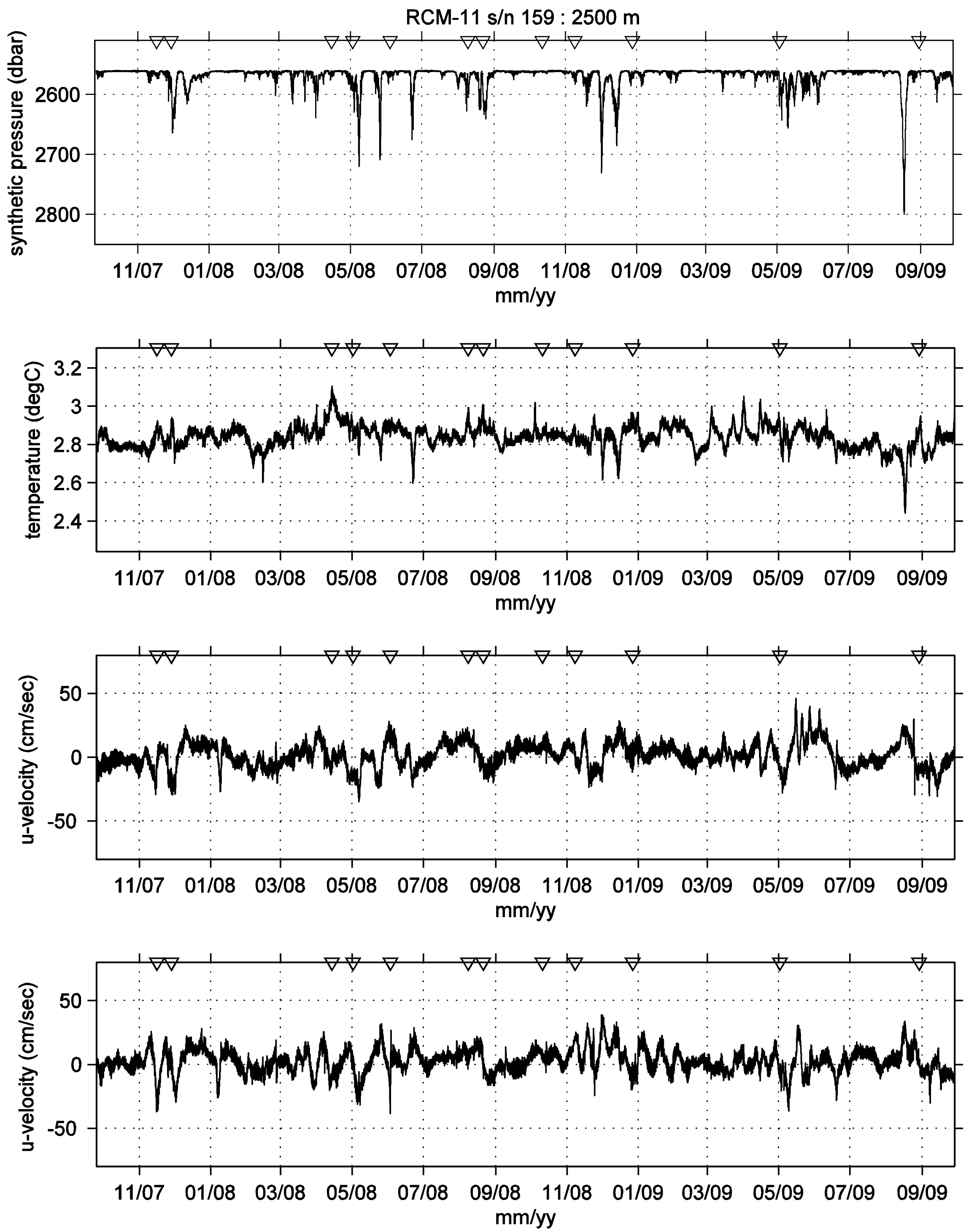

Figure C6. Current meter #159, positioned at 2500 meters.

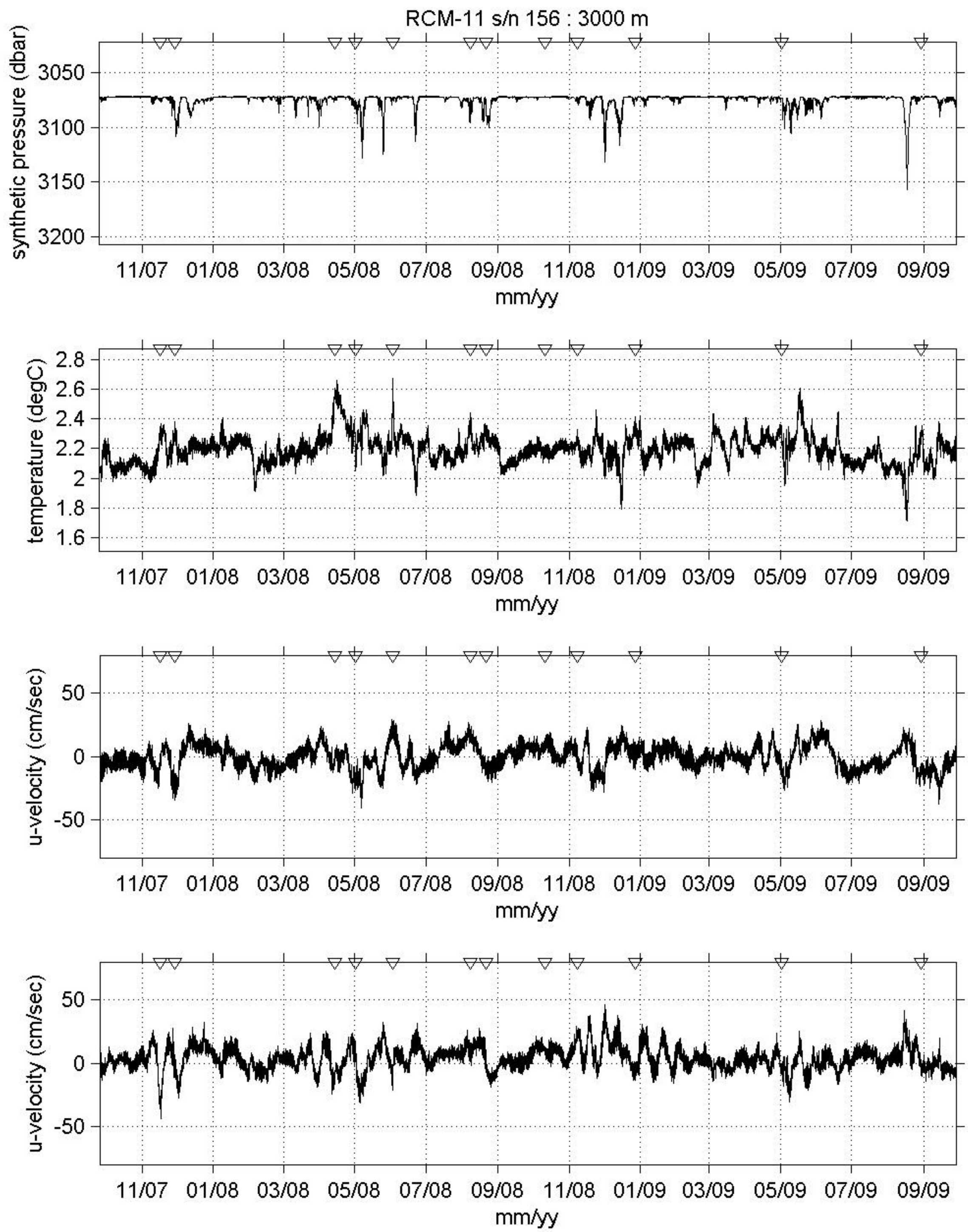

Figure C7. Current meter #156, positioned at 3000 meters.

Appendix D: Seabird SBE37 pressure or synthetic pressure (see Section 3.3), in situ temperature, and salinity records. Aanderaa RCM11 current meter synthetic pressure (see Section 3.3), in situ temperature, u-velocity and v-velocity records. On all plots, triangles designate positions in time of the 12 best anticyclones in the mooring record, see De Jong at al. (submitted) for details.

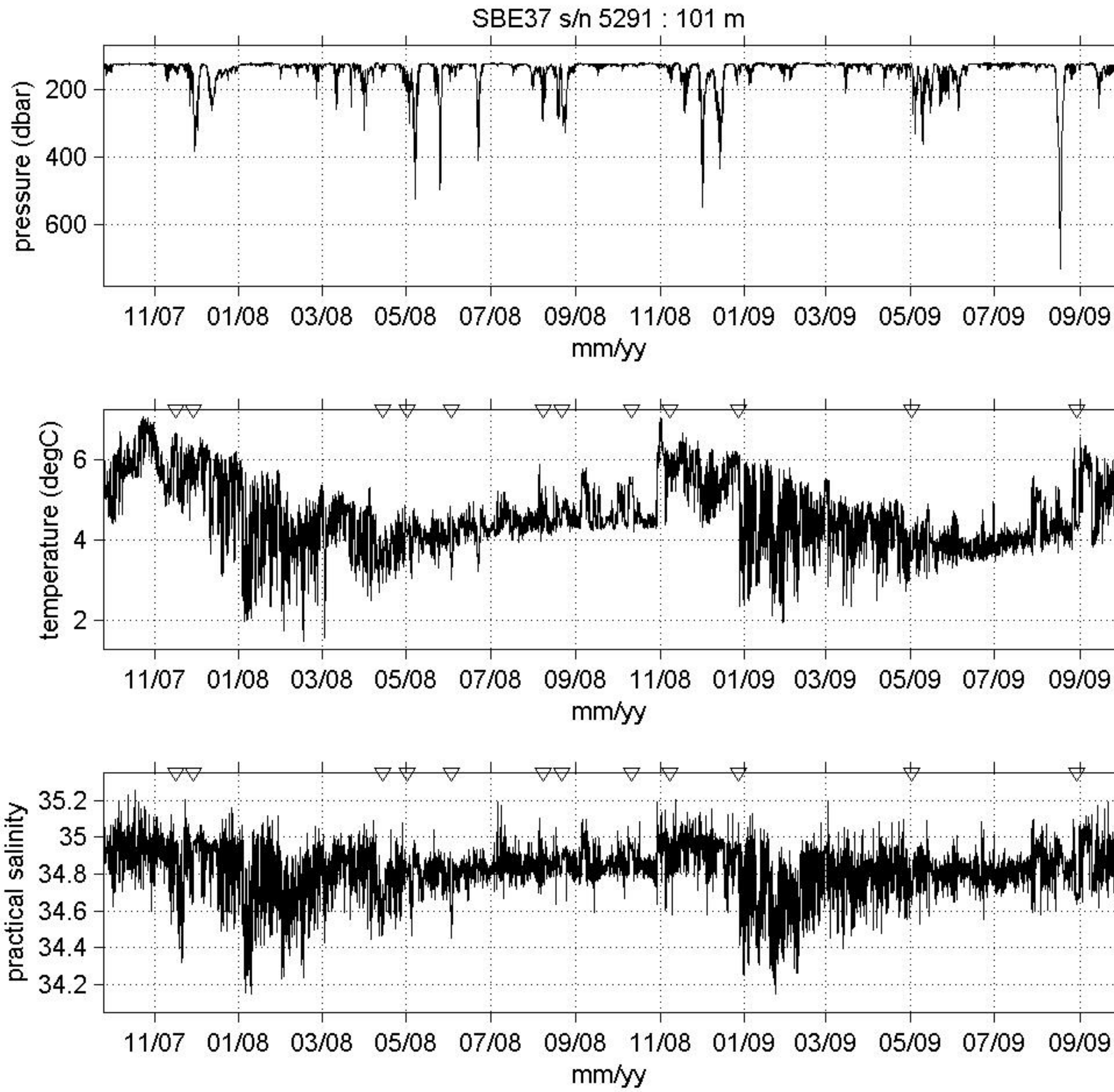

Figure D1. Microcat #5291, positioned at 101 meters.

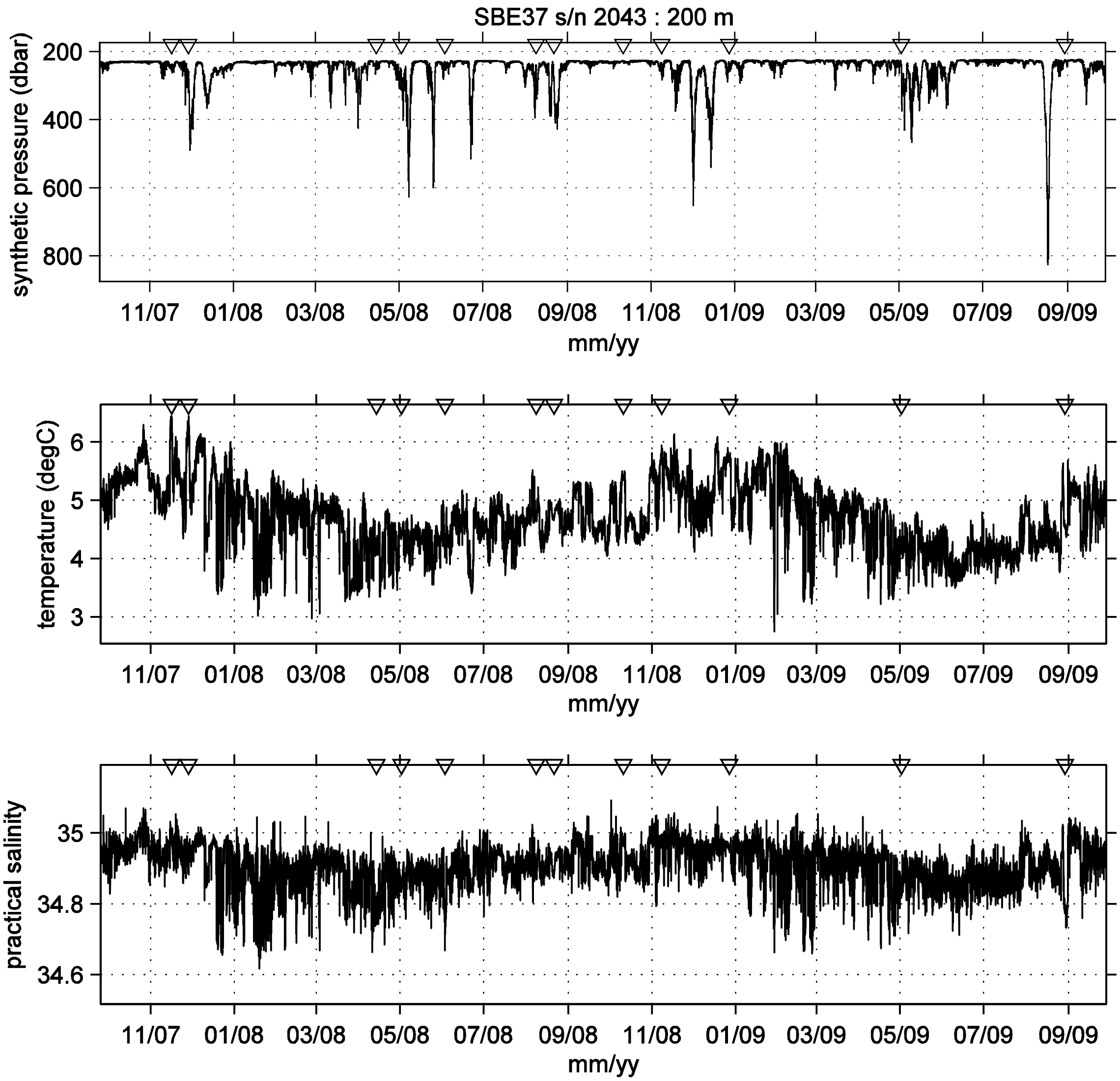

Figure D2. Microcat #2043, positioned at 200 meters.

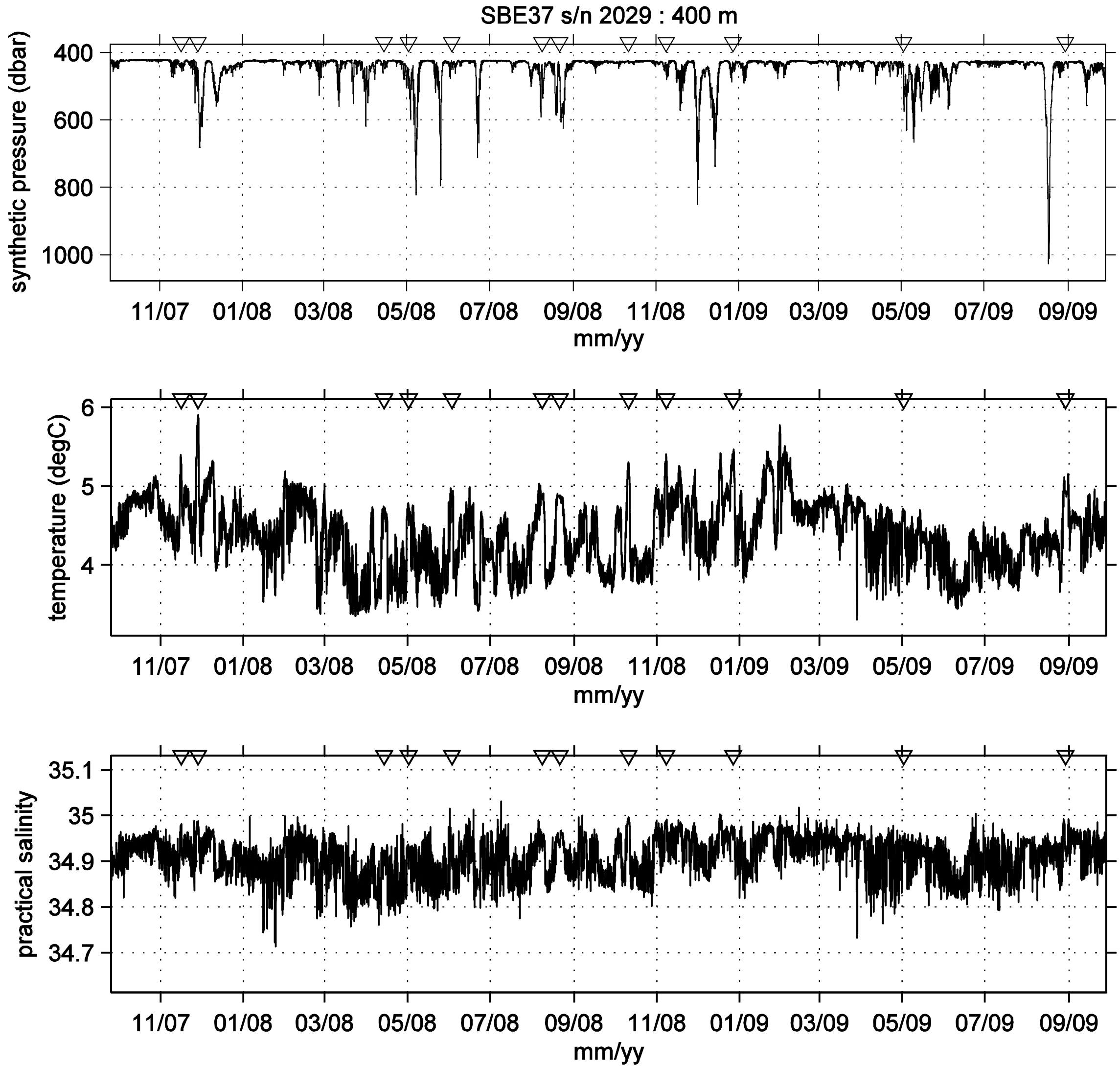

Figure D3. Microcat #2029, positioned at 400 meters.

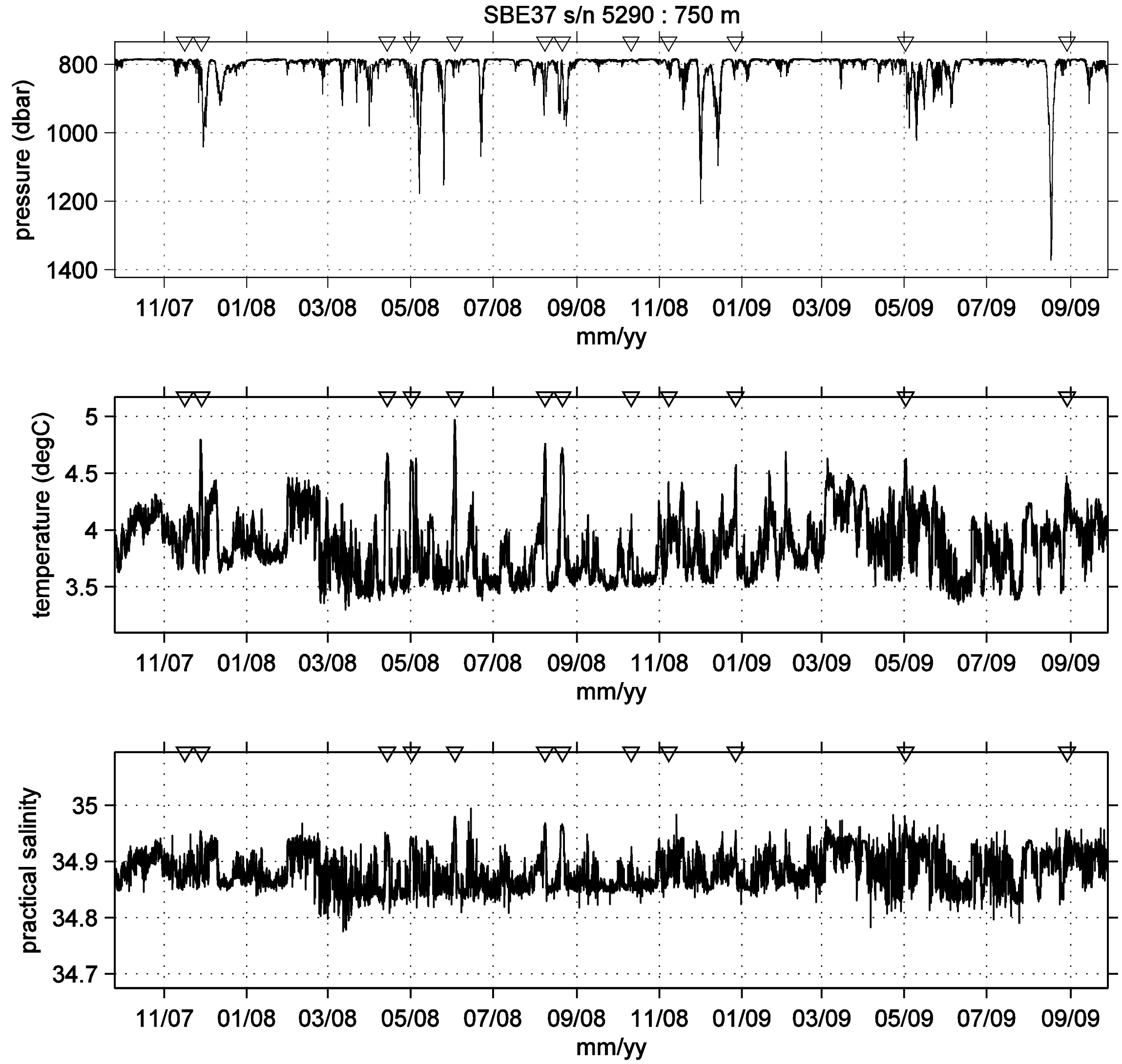

Figure D4. Microcat #5290, positioned at 750 meters.

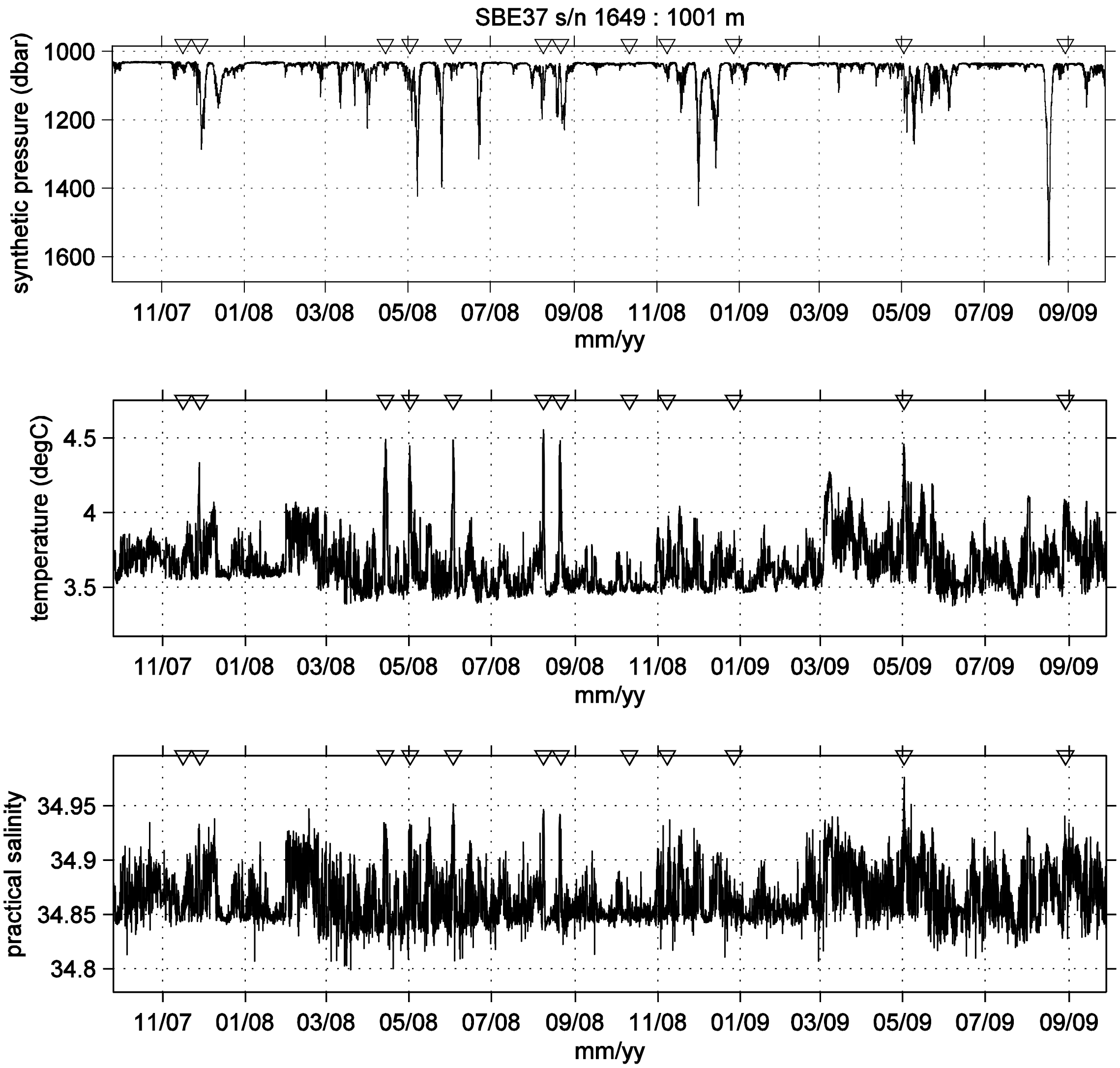

Figure D5. Microcat #1649, positioned at 1001 meters.

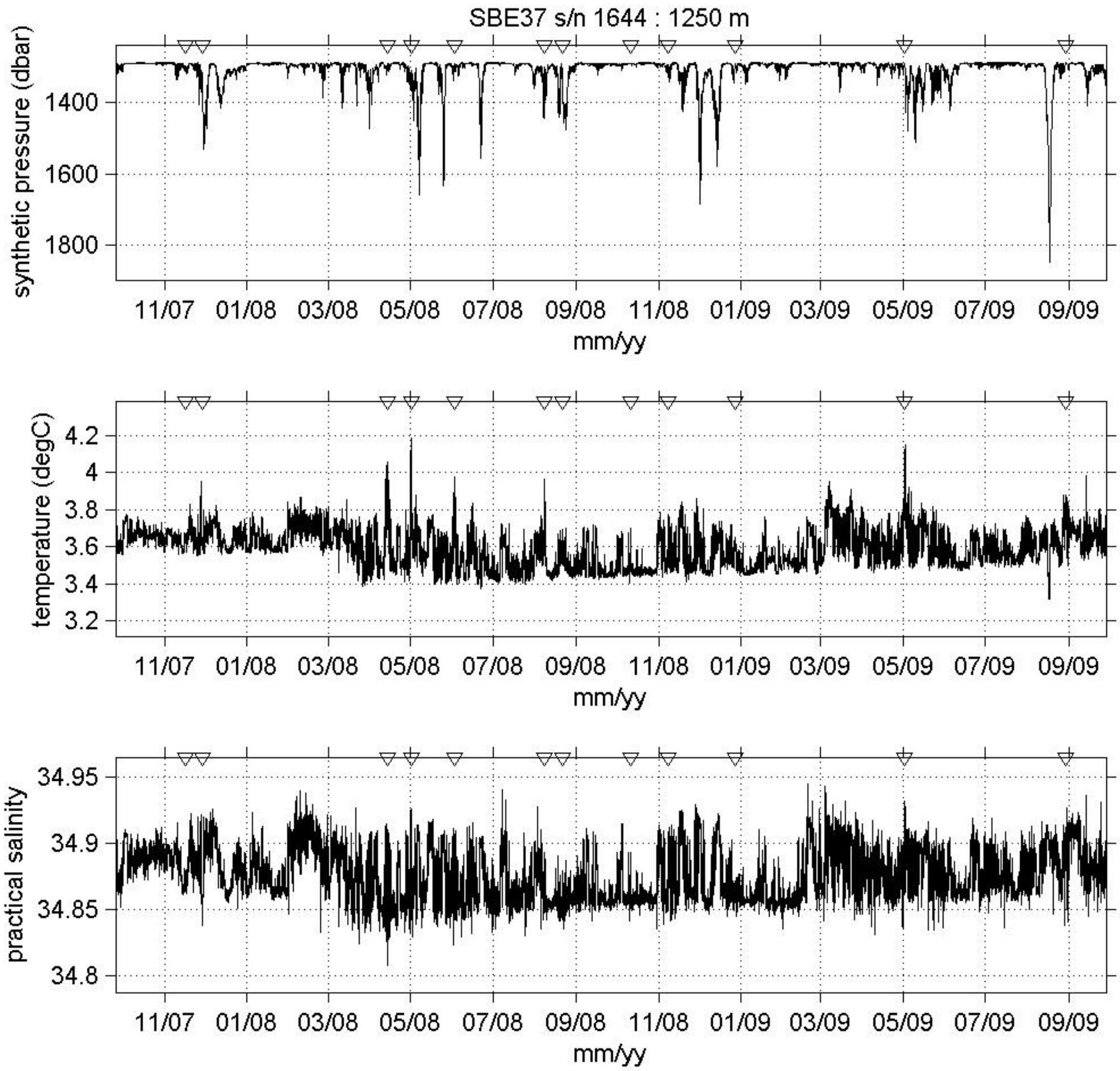

Figure D6. Microcat #1644, positioned at 1250 meters.

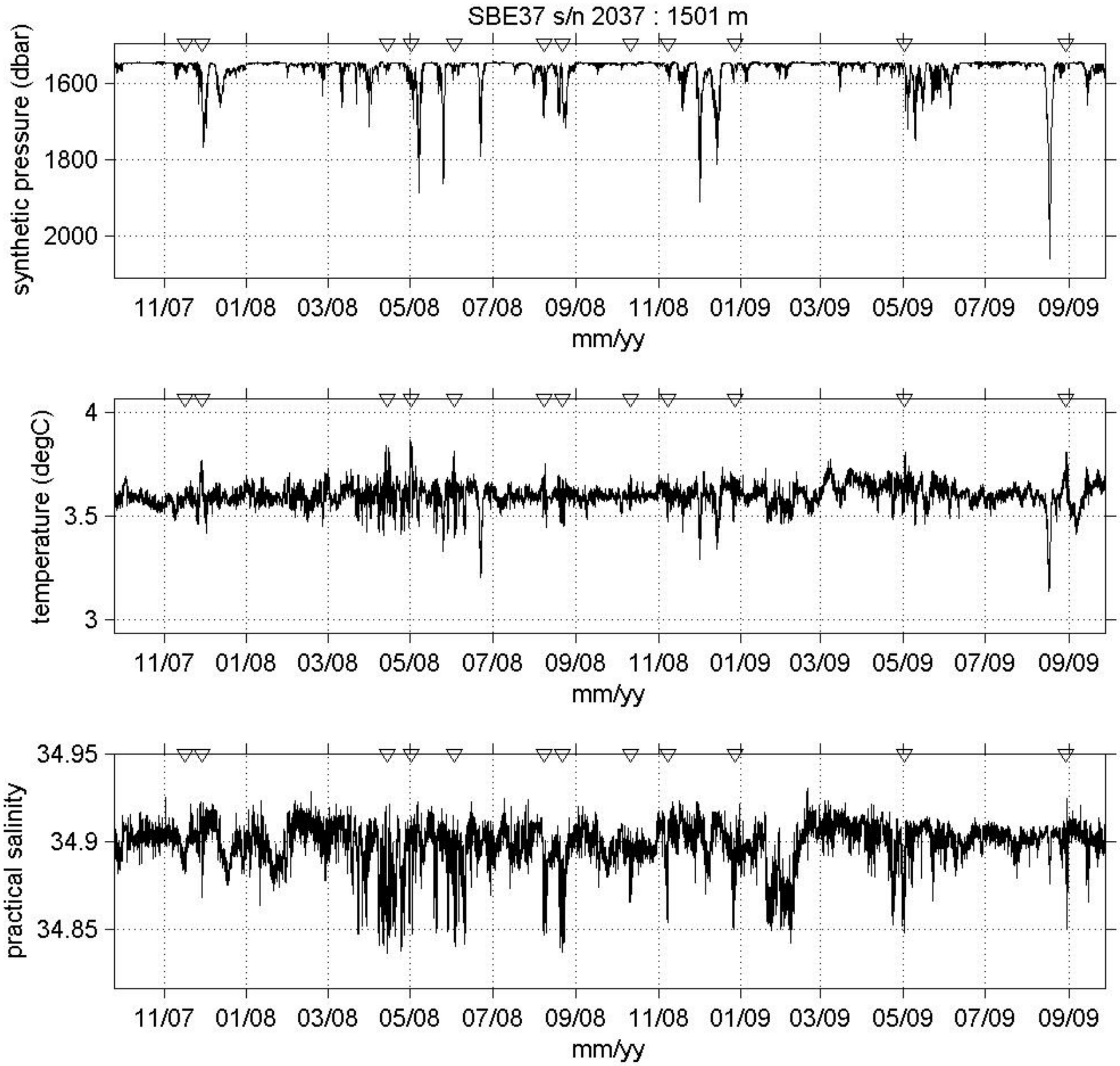

Figure D7. Microcat #2037, positioned at 1501 meters.

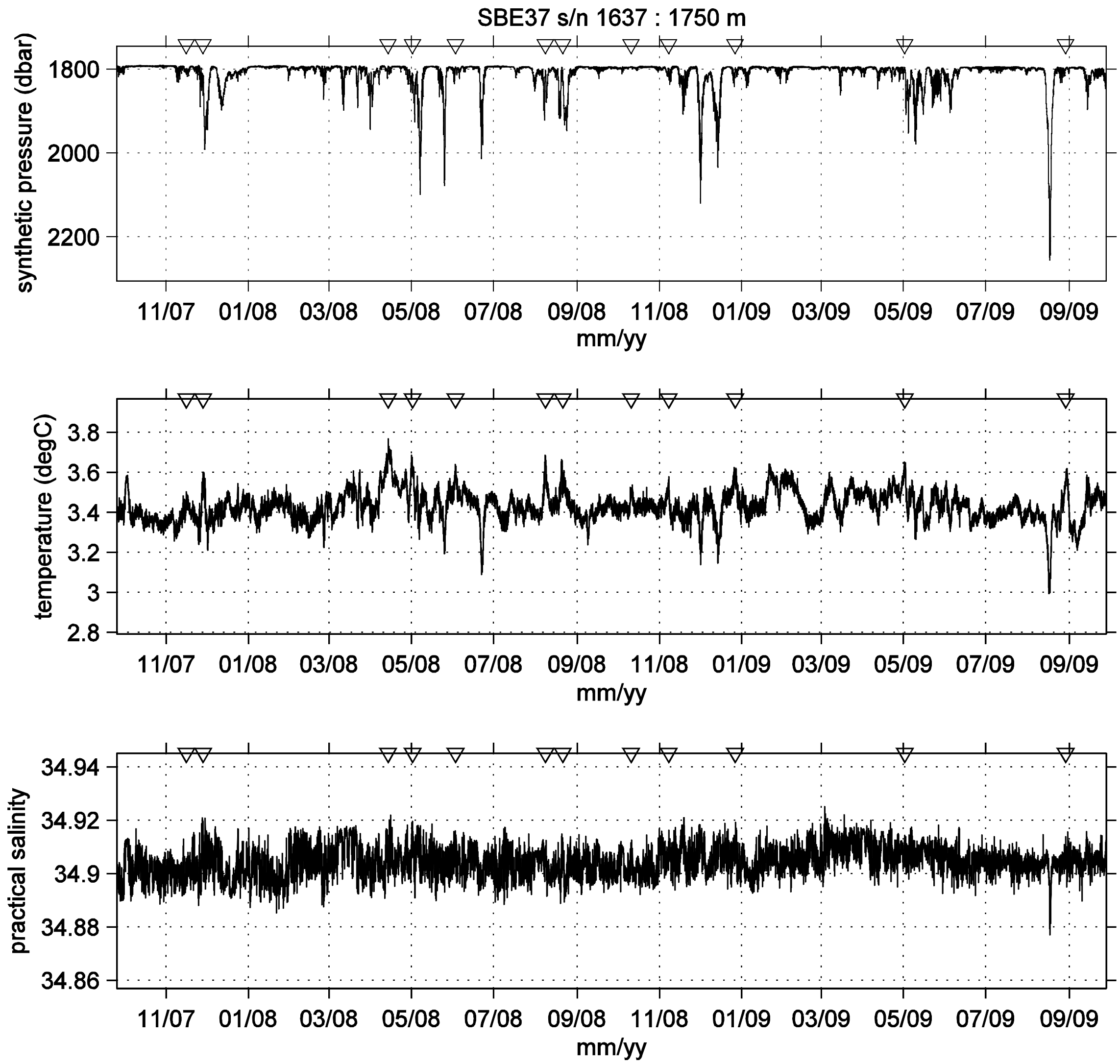

Figure D8. Microcat #1637, positioned at 1750 meters.

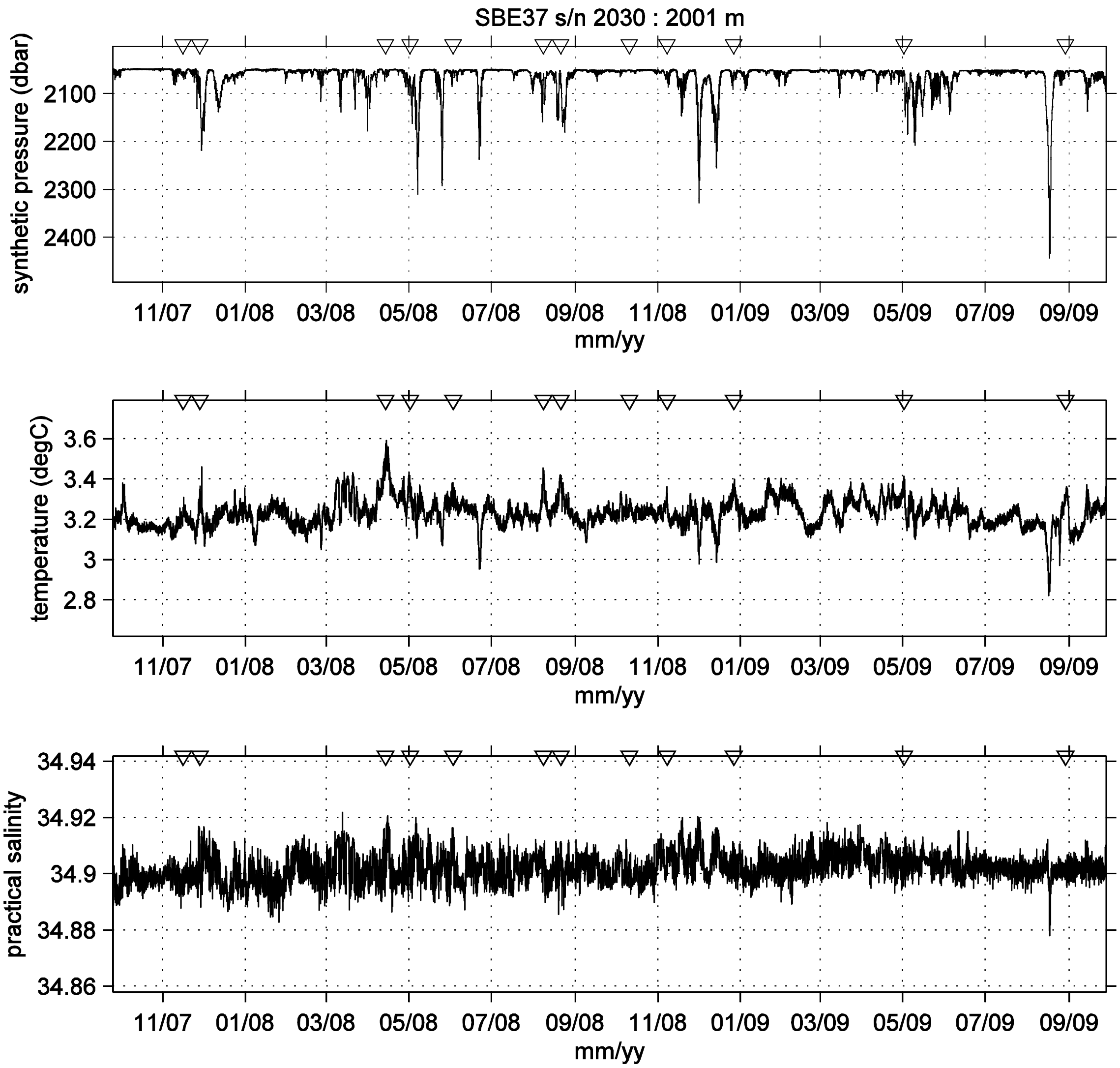

Figure D9. Microcat #2030, positioned at 2001 meters.

Appendix E: CTD station data.

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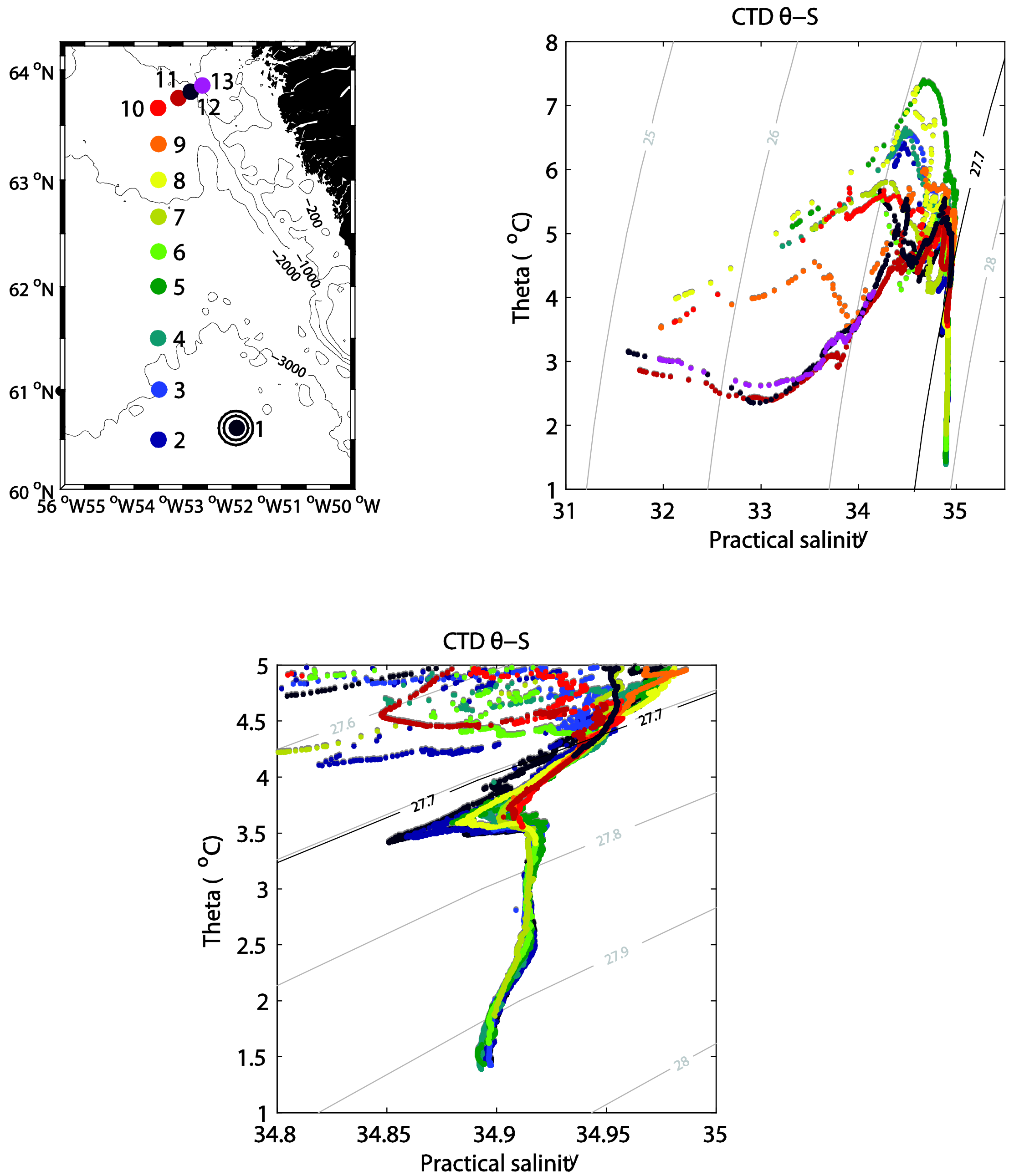

Figure E1. (a) CTD station locations and numbers, (b) θ-S diagram, (c) θ-S with axes pared to isolate deep θ-S variability.

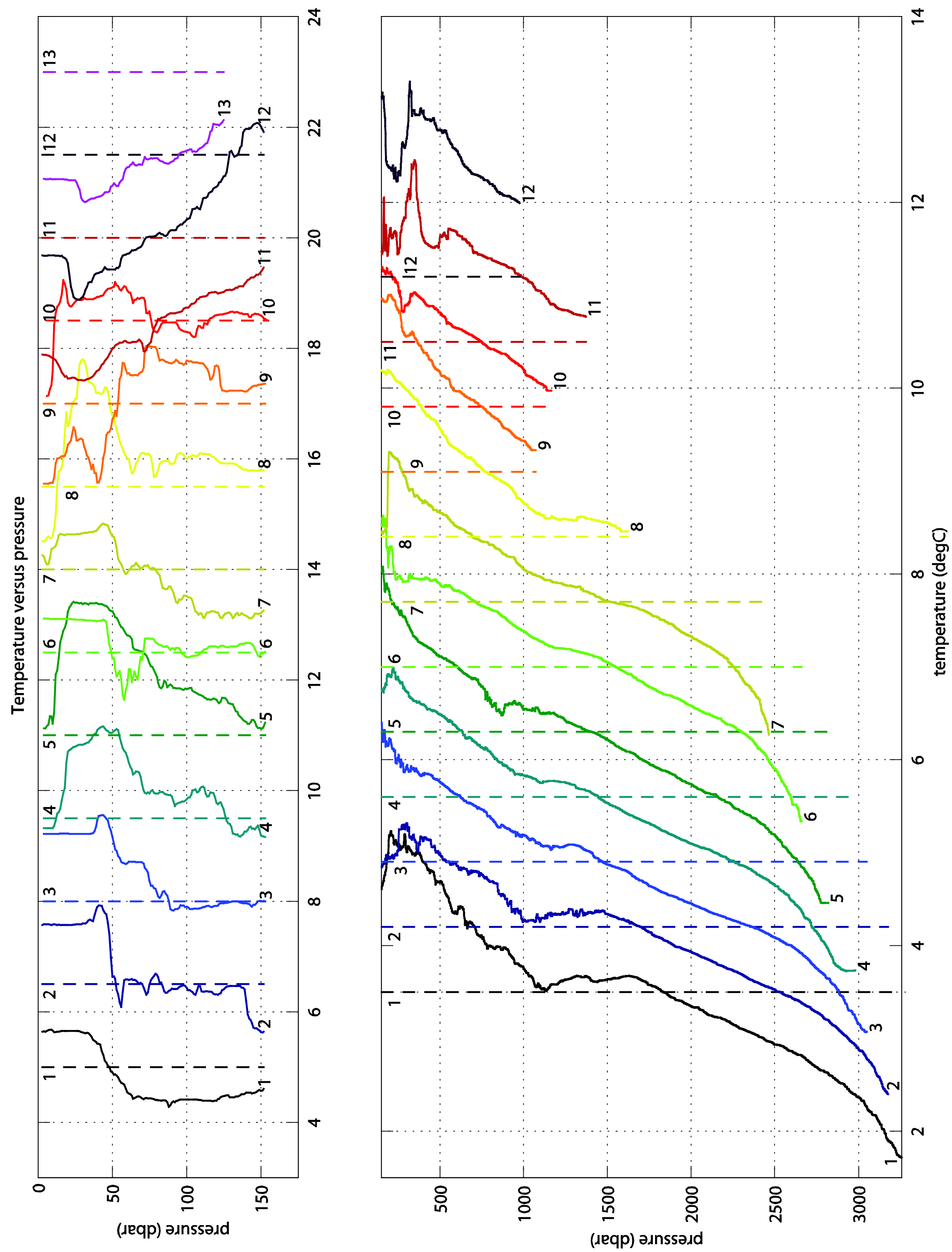

Figure E2. (left, top) Temperature versus pressure: surface – 150 m, (right, bottom) Temperature versus pressure: below 150 m. Numbers refer to stations cast number show in E1, where #1 is the cast at the mooring site, and #13 is the cast nearest the coast of Greenland. In the 0-150 meter (150 m – bottom) data, stations have been offset by 1.5°C (0.7°C), so that 1.5°C (0.7°C) times N-1 has been added to each cast after the cast at station #1, where N is the station number. Reference lines have been put in for each cast that show the offset for each cast + a uniform temperature cast of 5°C (3.5°C). The reference casts are annotated with station number at the top of the cast, actual cast is marked at the bottom of the cast.

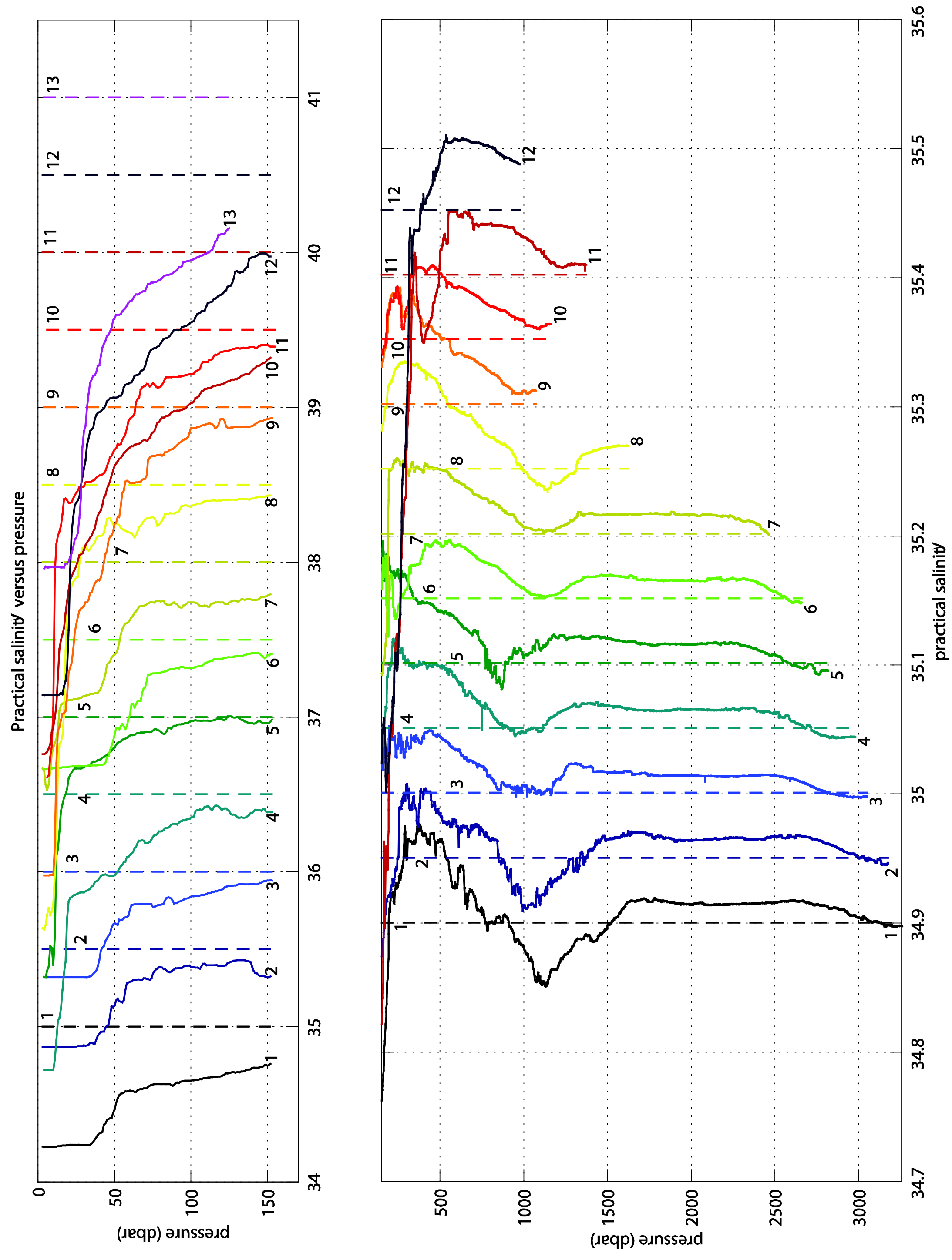

Figure E3. (left, top) Practical salinity versus pressure: surface – 150 m, (right, bottom) Practical salinity versus pressure: below 150 m. Numbers refer to stations cast number show in E1, where #1 is the cast at the mooring site, and #13 is the cast nearest the coast of Greenland. In the 0-150 meter (150 m – bottom) data, stations have been offset by 0.5 (0.05), so that 0.5 (0.05) times N-1 has been added to each cast after the cast at station #1, where N is the station number. Reference lines have been put in for each cast that show the offset for each cast + a uniform salinity cast of 35.00 (34.90). The reference casts are annotated with station number at the top of the cast, actual cast is marked at the bottom of the cast.

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Appendix F: Summary plot of all APEX trajectories, and a set of four individual plots for each APEX: (a) float trajectory colored by time (blue is the earliest position, red is the most recent position, with positions marked by profile numbers) along with historical data station locations used to calibrate the APEX data; (b) θ-S diagram color coded by time similar to (a); the fit of APEX data compared with historical salinity data, including error estimates, along two θ surfaces; and (d) drift estimated of the APEX to historical data fits shown in (c) in conductivity and salinity space. All individual APEX plots are references by WMO number, see Table A5. Other plots (such as salinity and temperature versus time) are available at the individual drifter URLs listed in Table A5.

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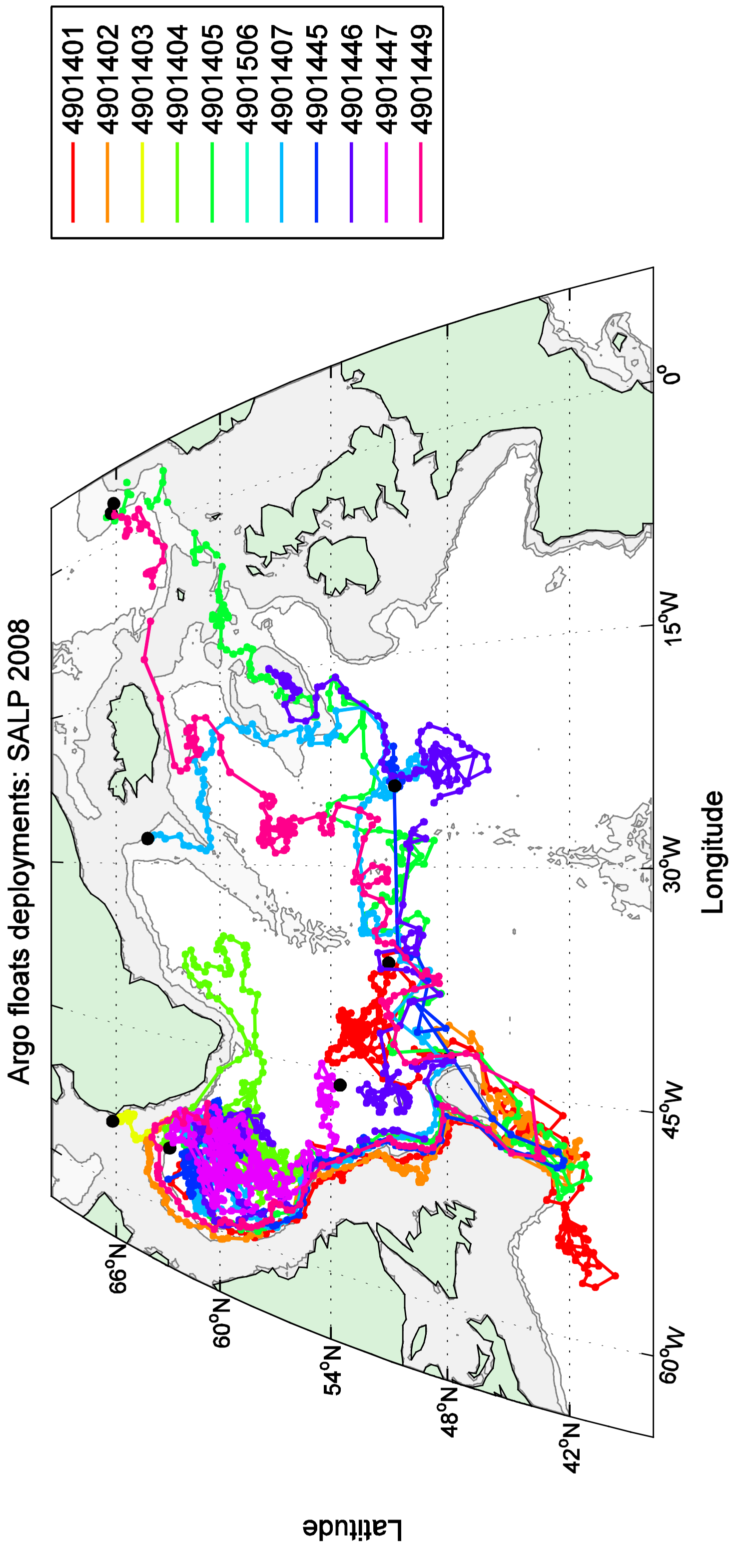


Figure F1. Composite plot of all APEX trajectories collected as a part of this experiment, labeled by WMO ascension number (See Table A5).

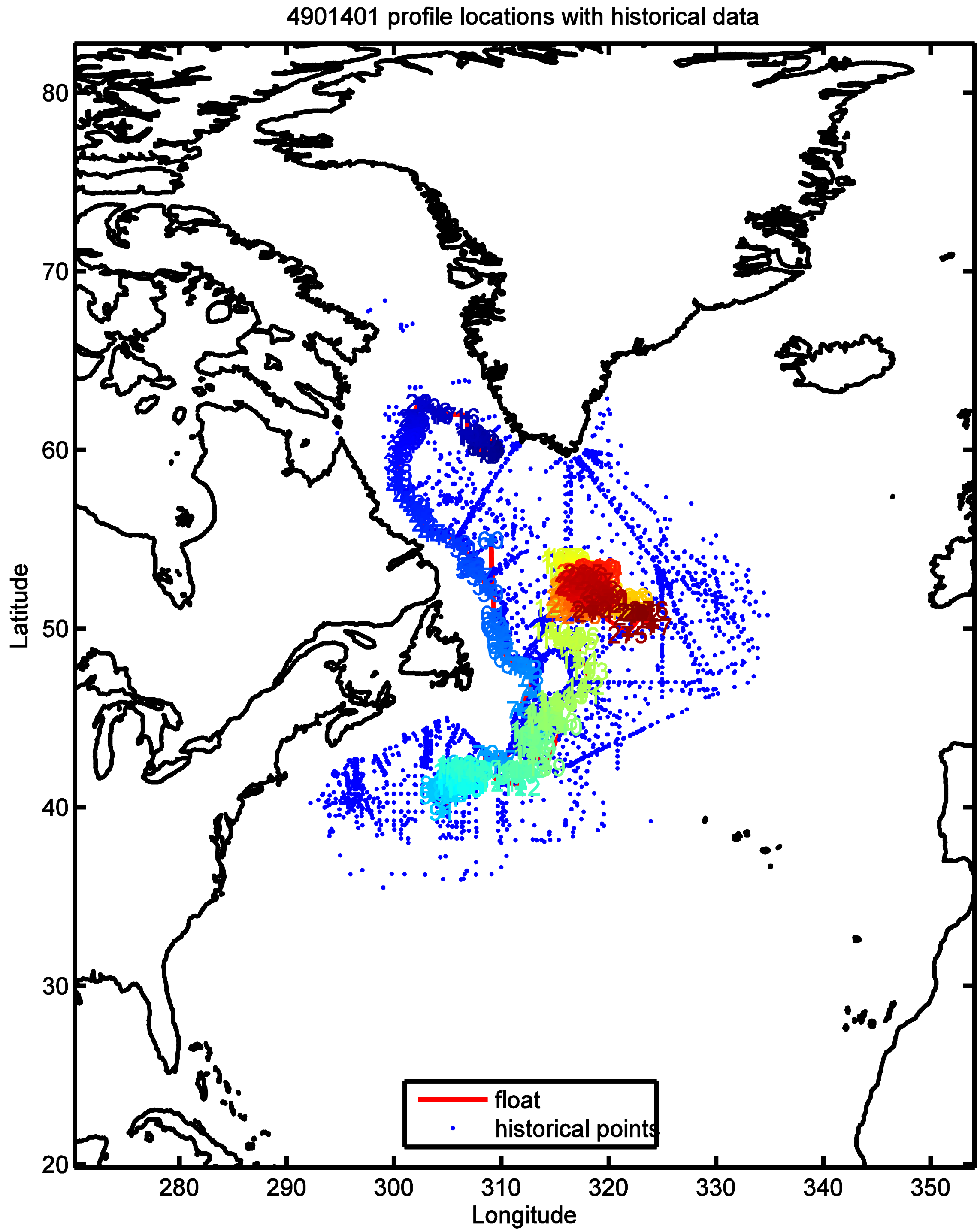


Figure F2a. APEX s/n 5261 / WMO #4901401.

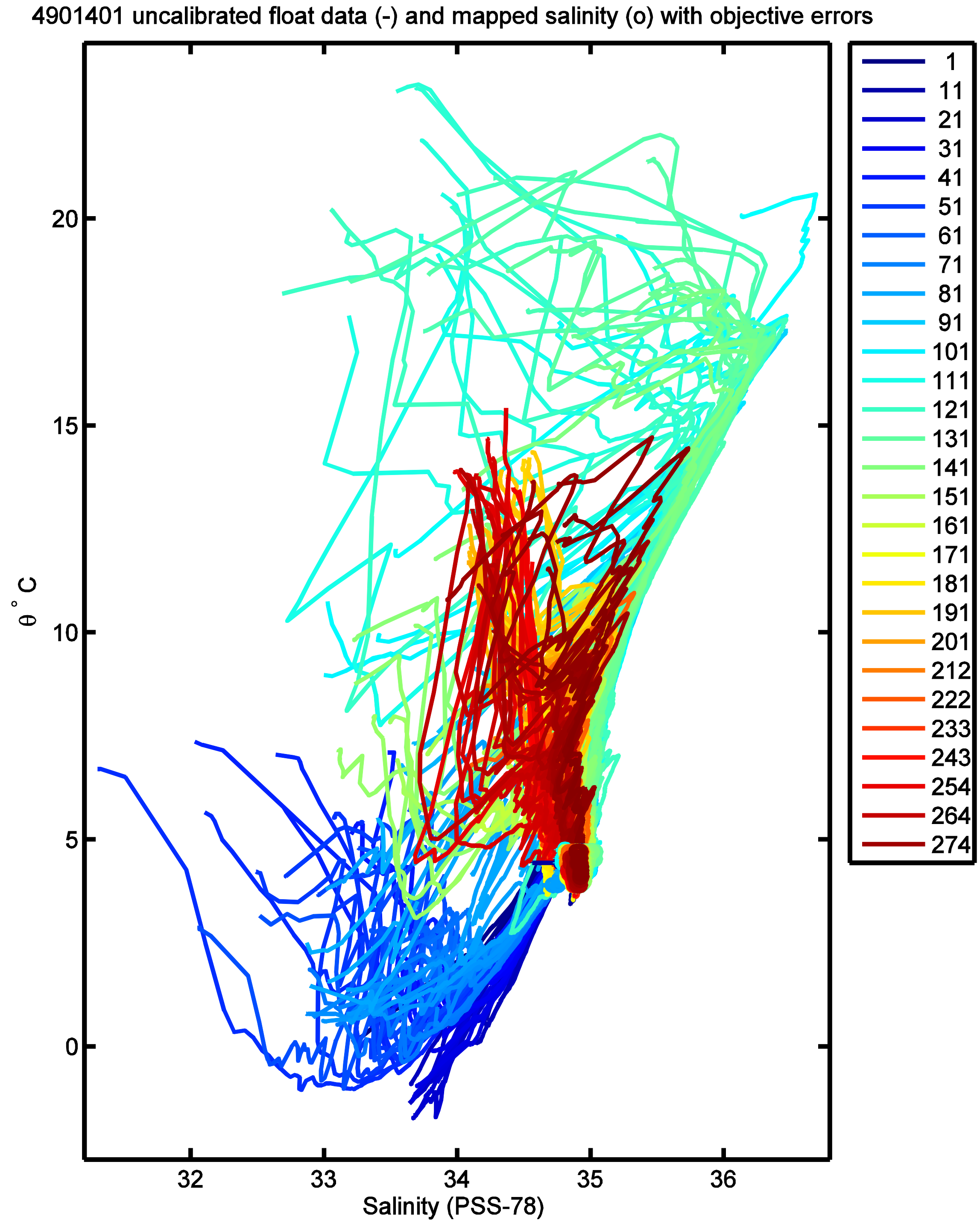


Figure F2b. APEX s/n 5261 / WMO #4901401.

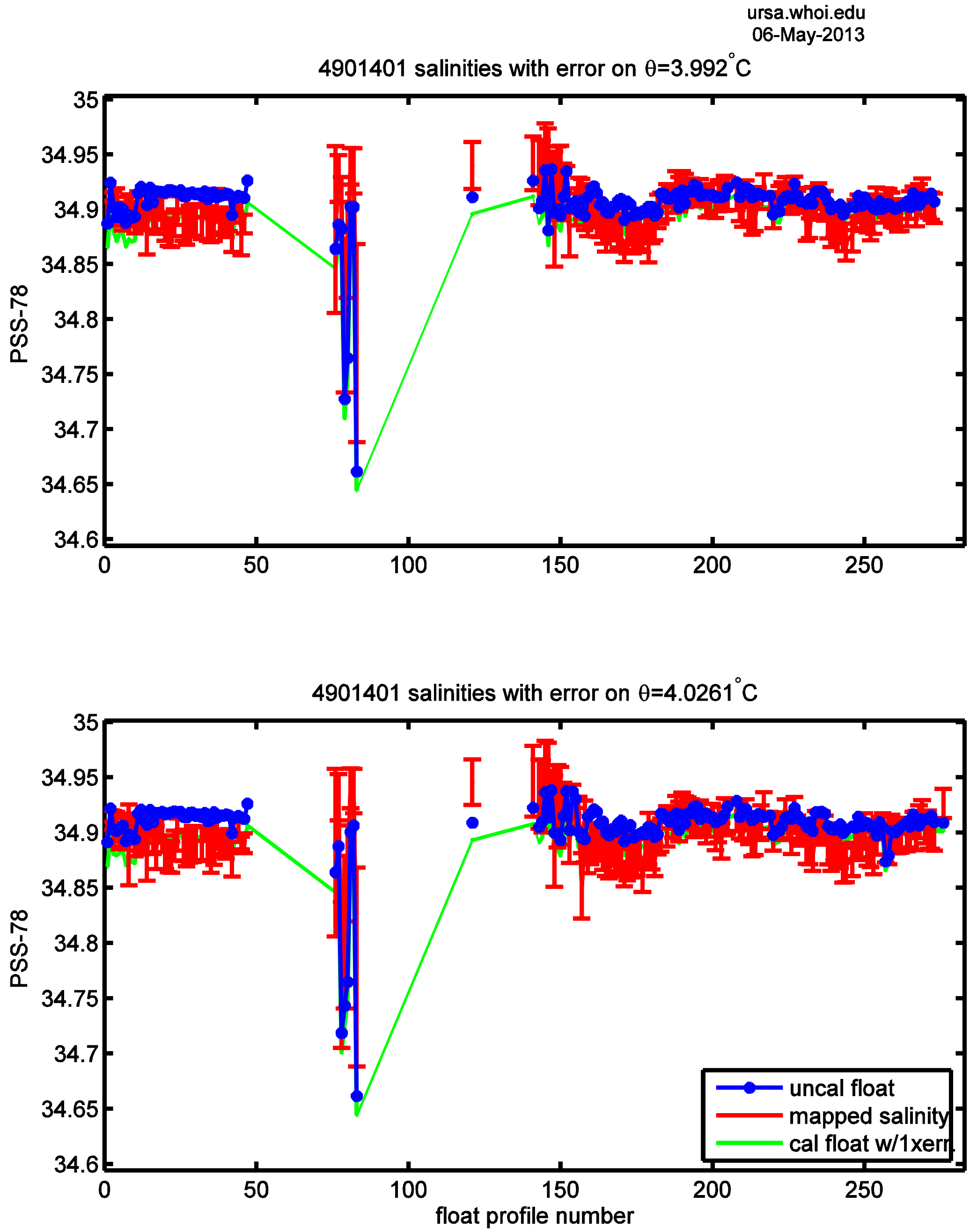


Figure F2c. APEX s/n 5261 / WMO #4901401.

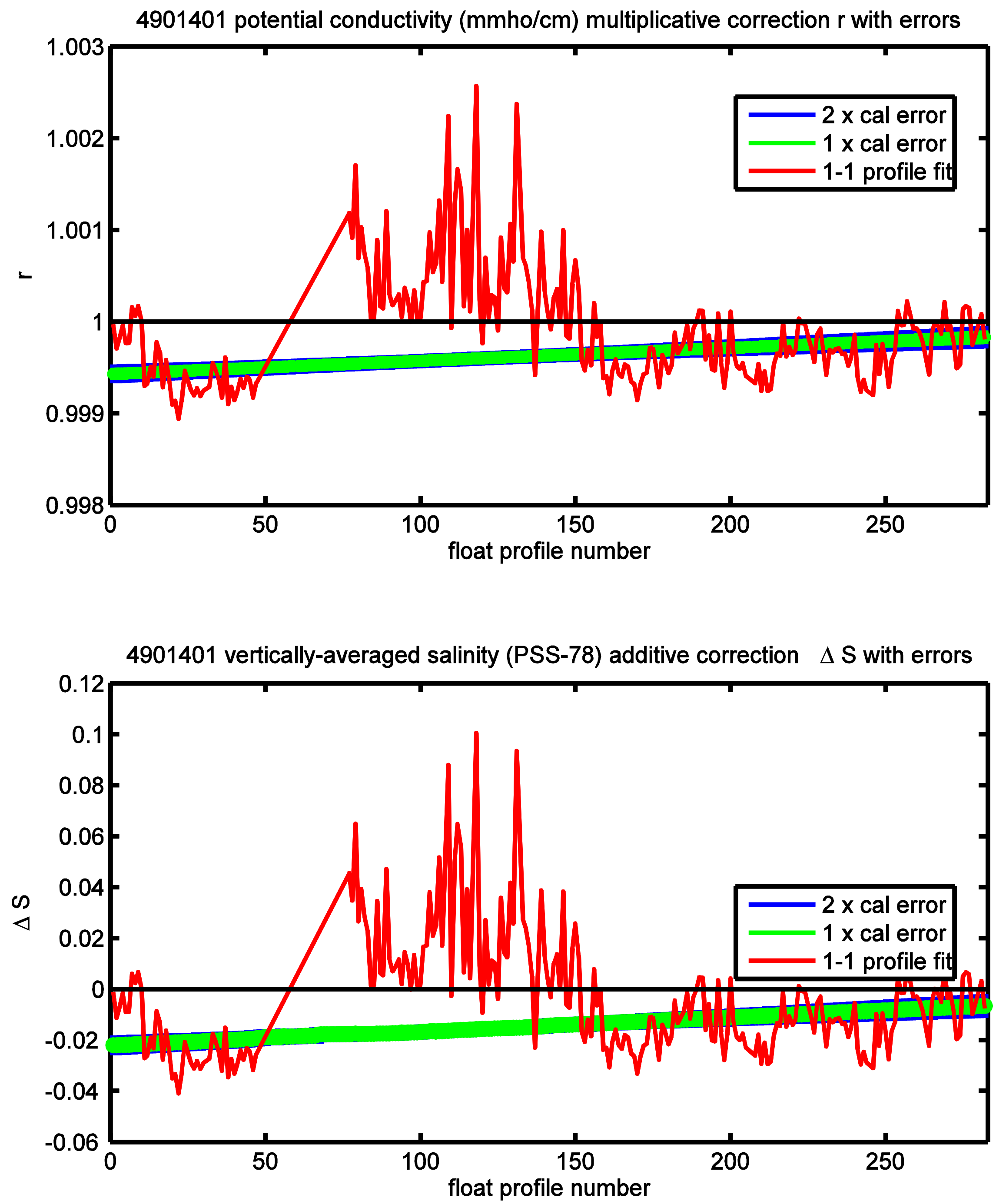


Figure F2d. APEX s/n 5261 / WMO #4901401.

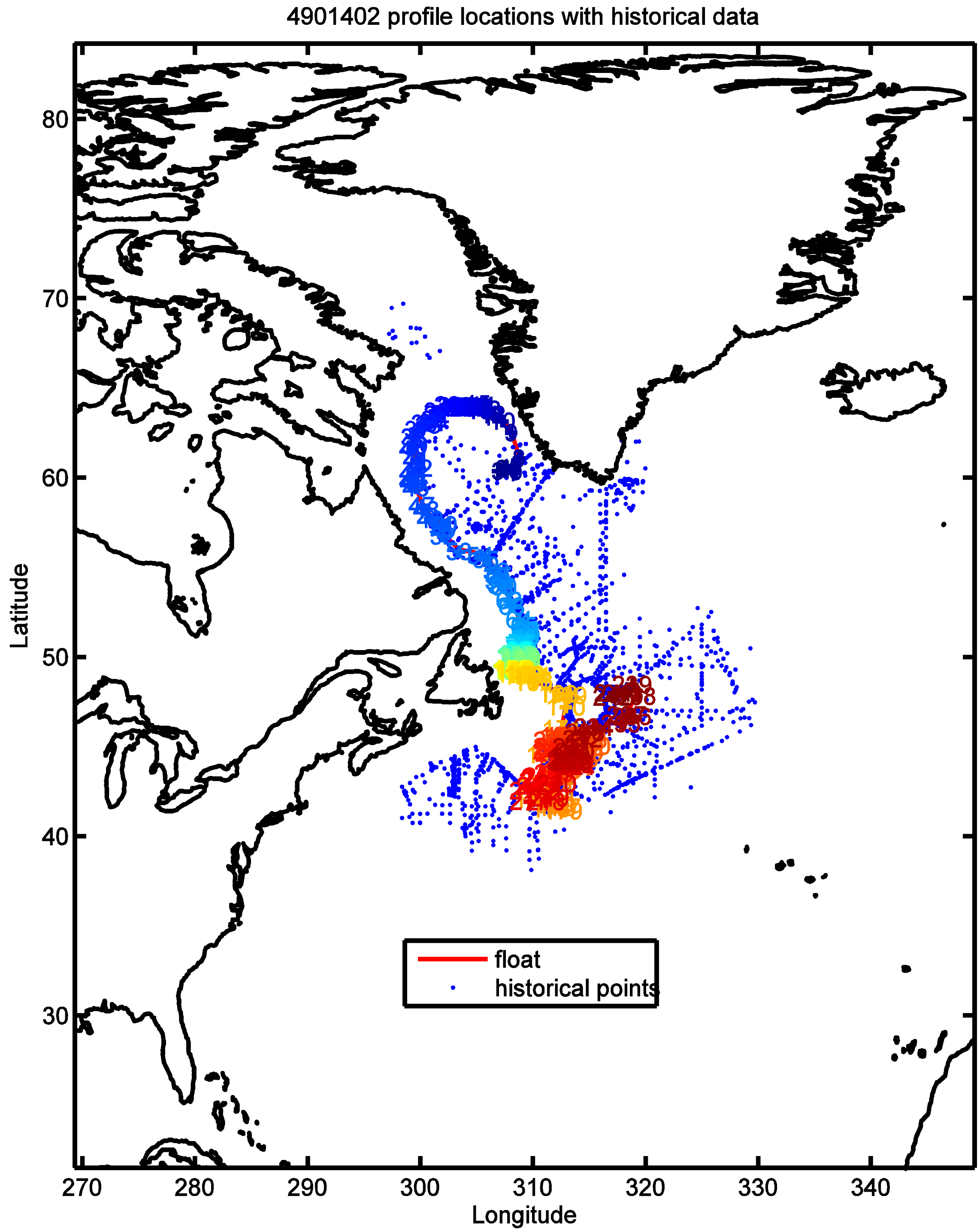


Figure F3a. APEX s/n 5262 / WMO #4901402.

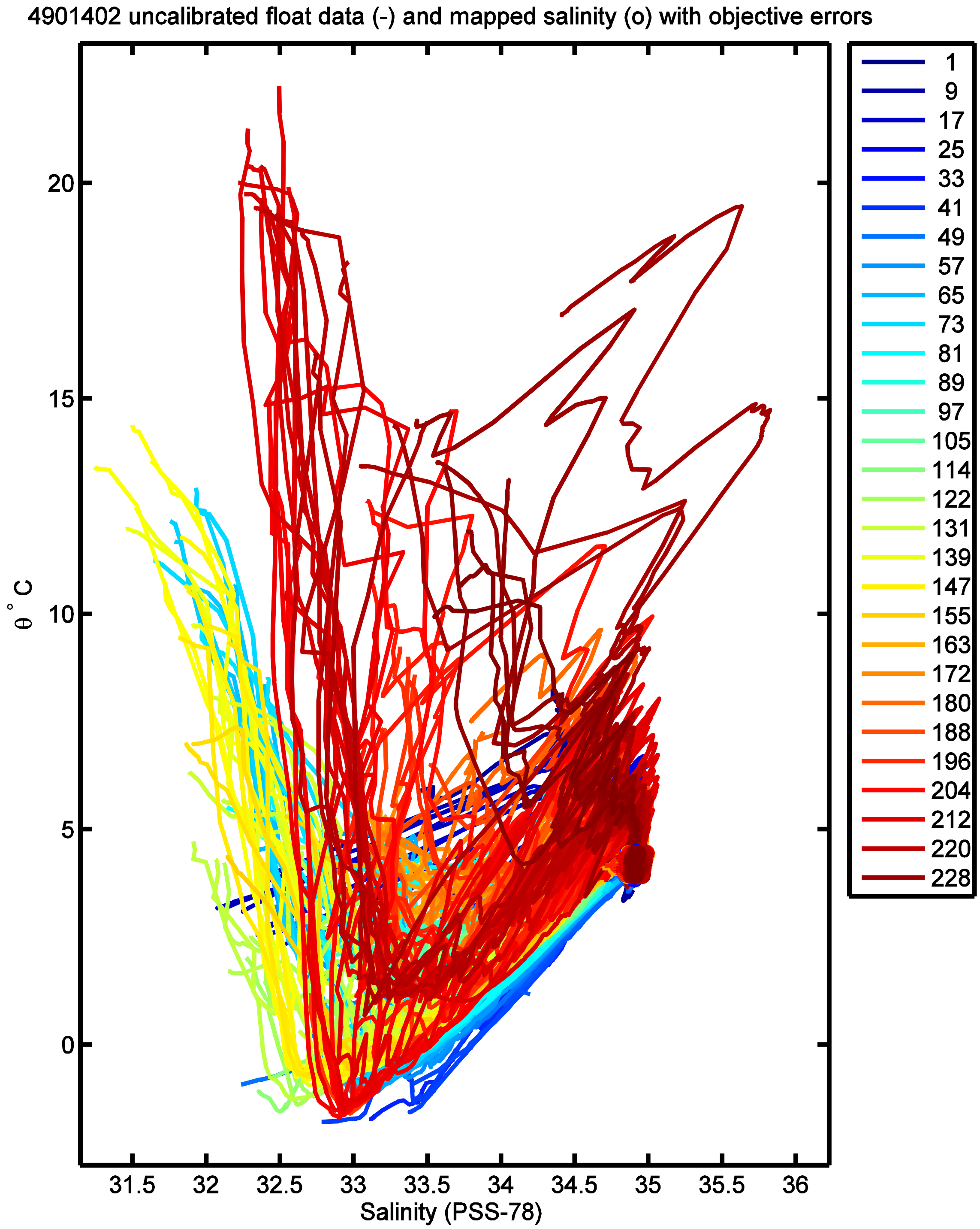


Figure F3b. APEX s/n 5262 / WMO #4901402.

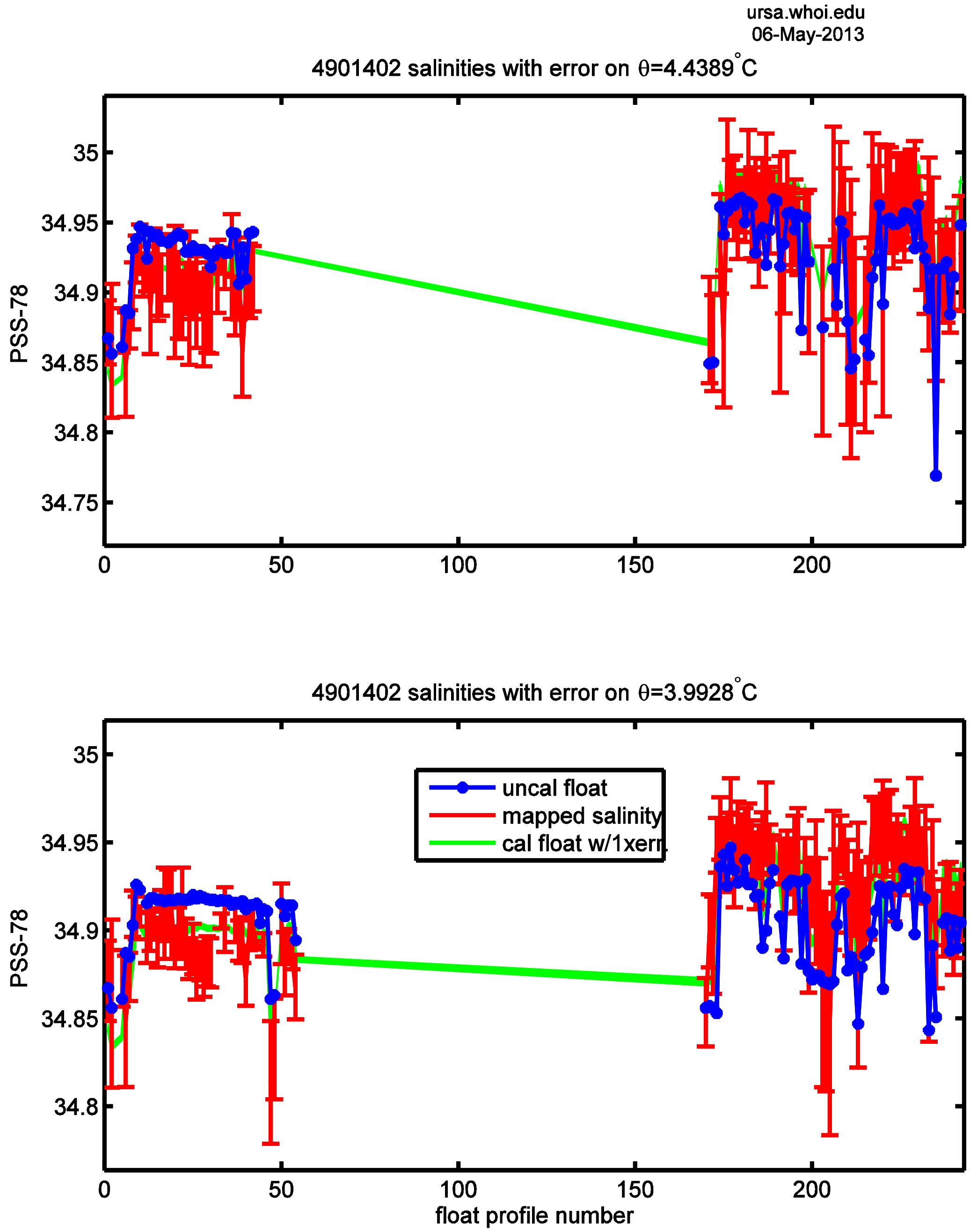
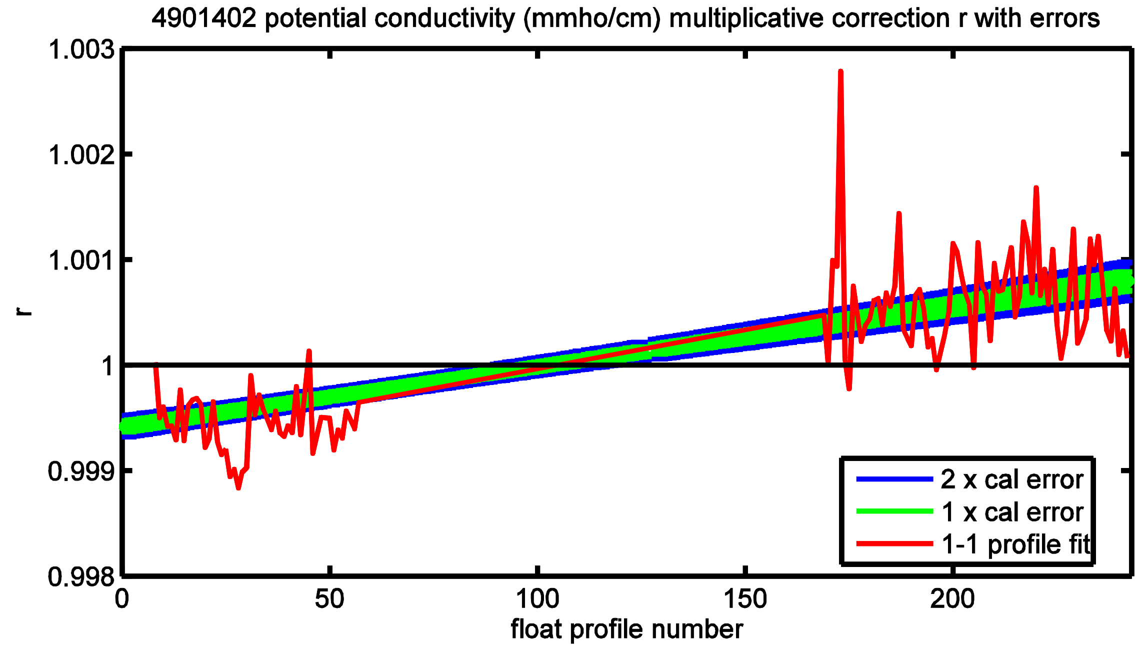


Figure F3c. APEX s/n 5262 / WMO #4901402.



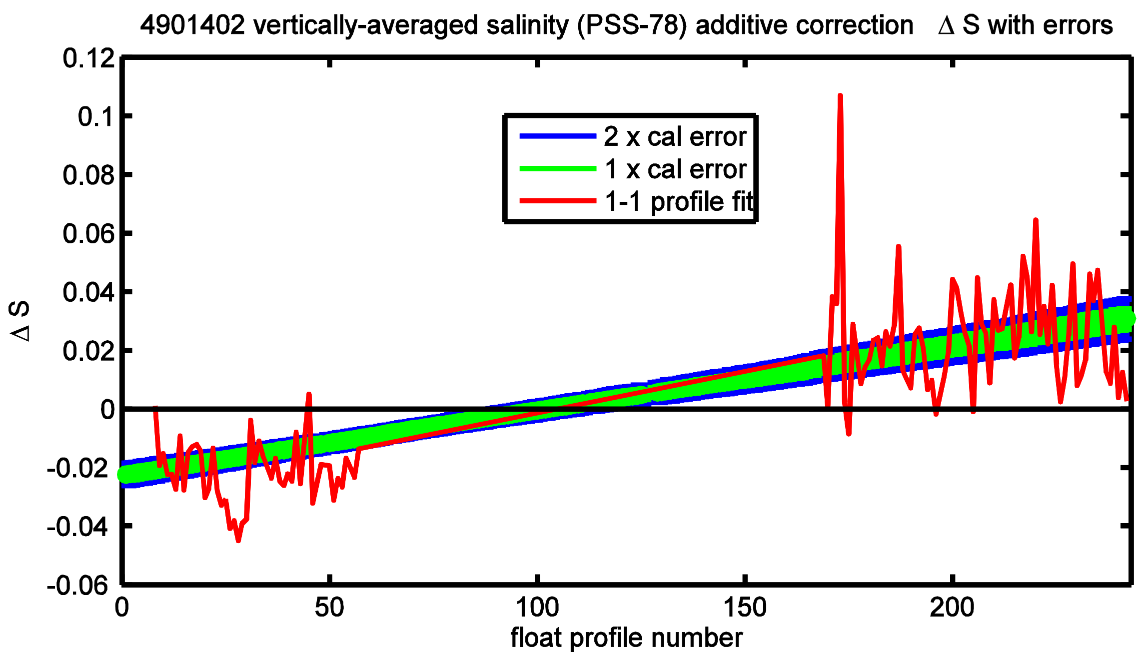


Figure F3d. APEX s/n 5262 / WMO #4901402.

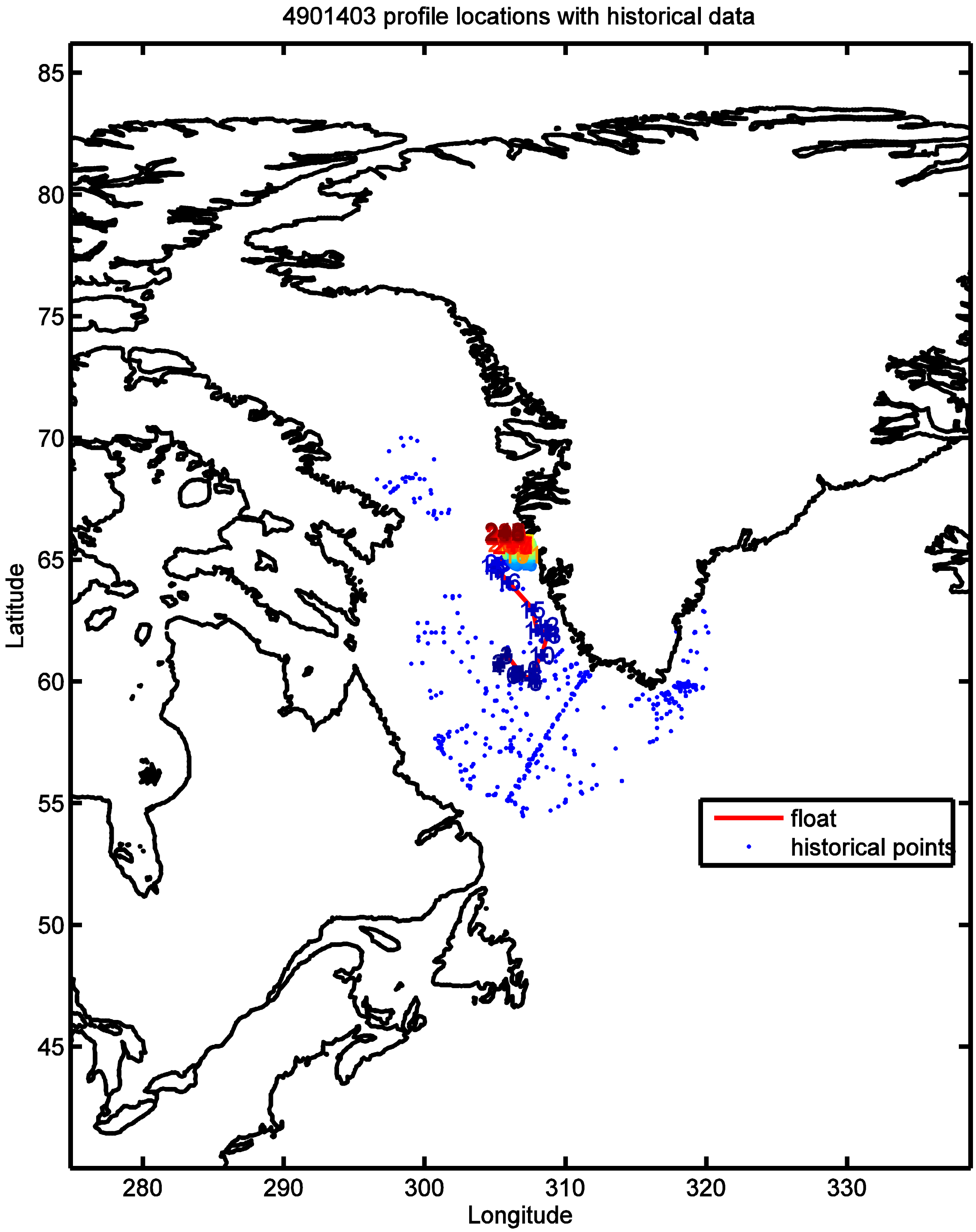


Figure F4a. APEX s/n 5263 / WMO #4901403.

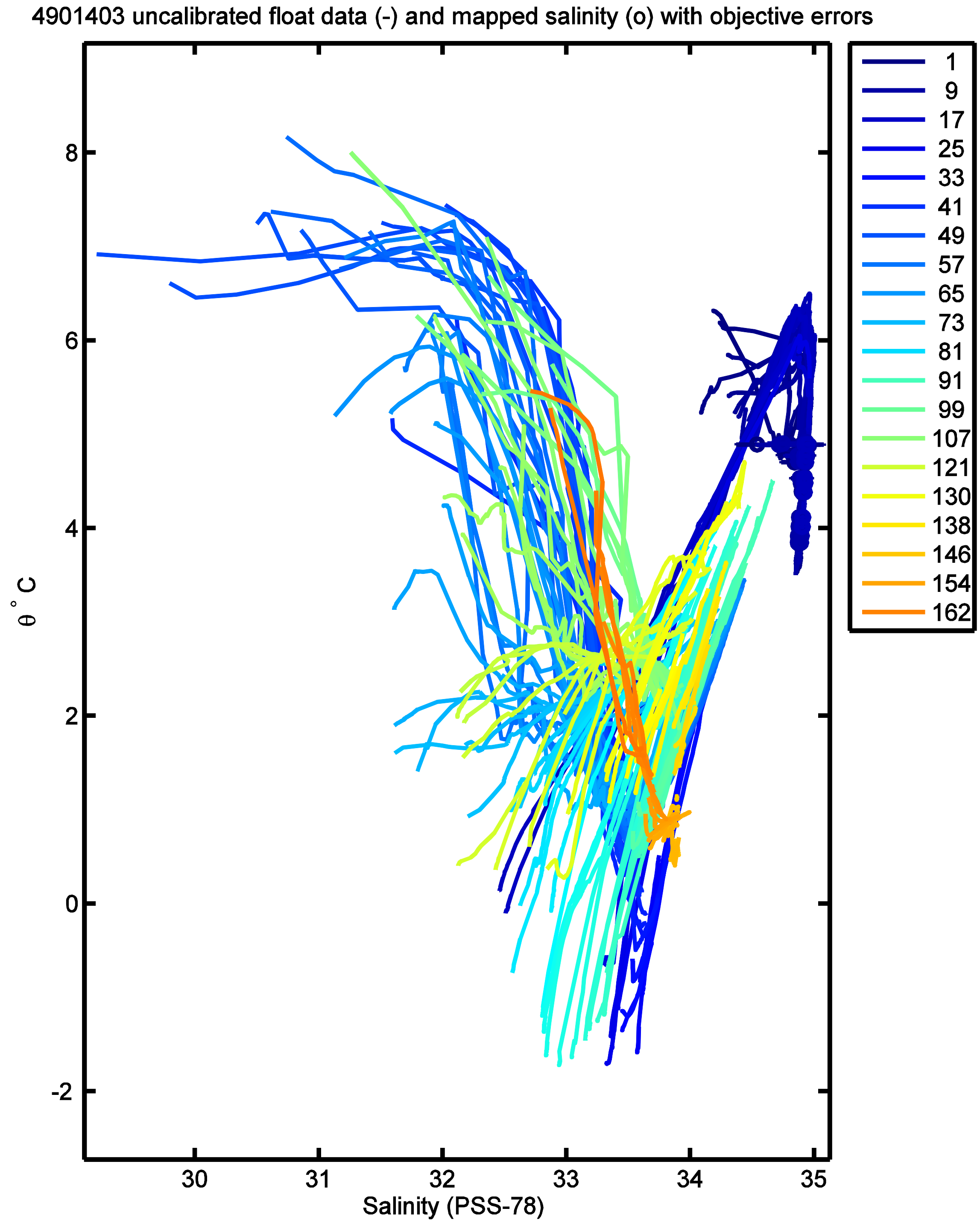


Figure F4b. APEX s/n 5263 / WMO #4901403.

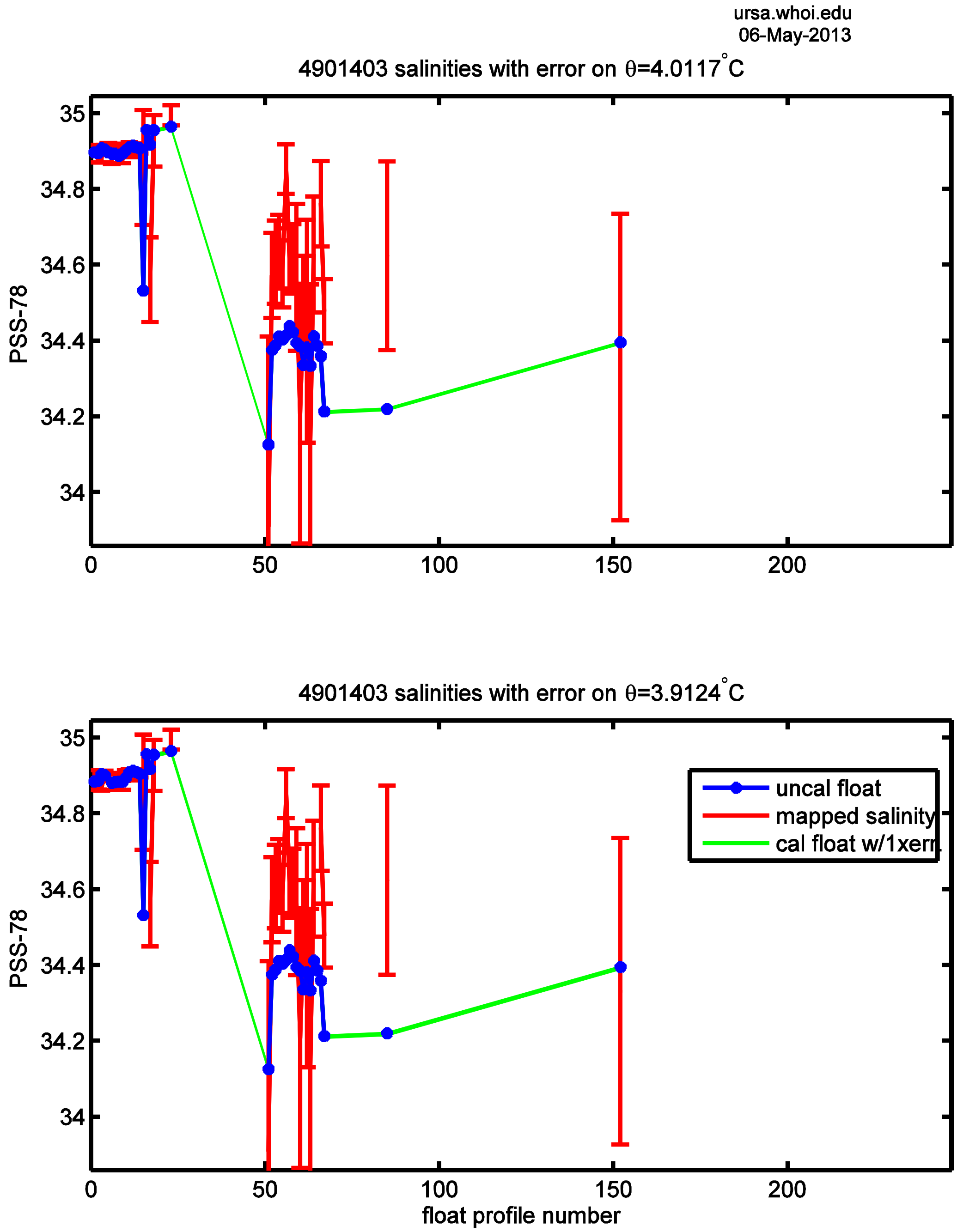


Figure F4c. APEX s/n 5263 / WMO #4901403.

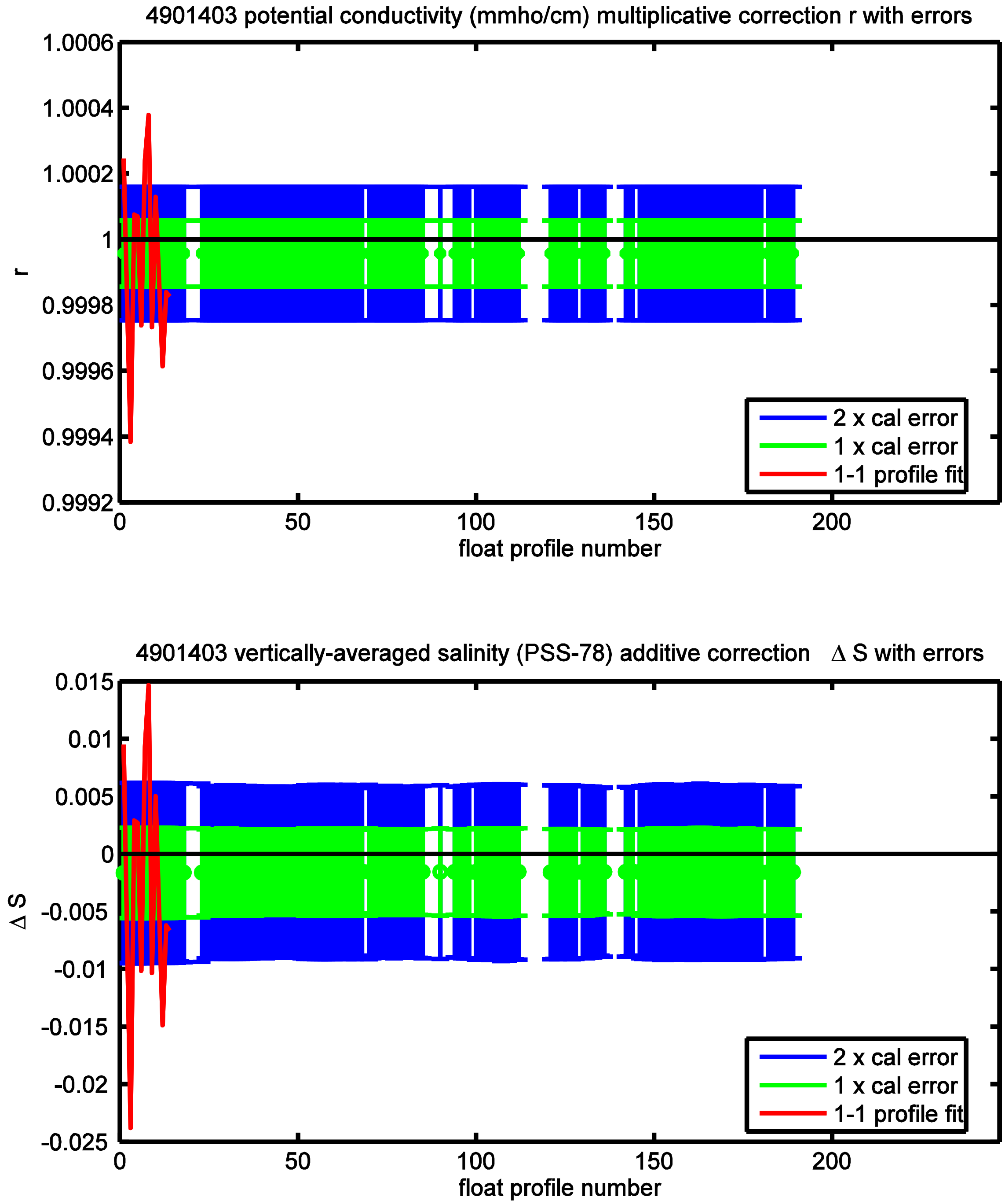


Figure F4d. APEX s/n 5263 / WMO #4901403.

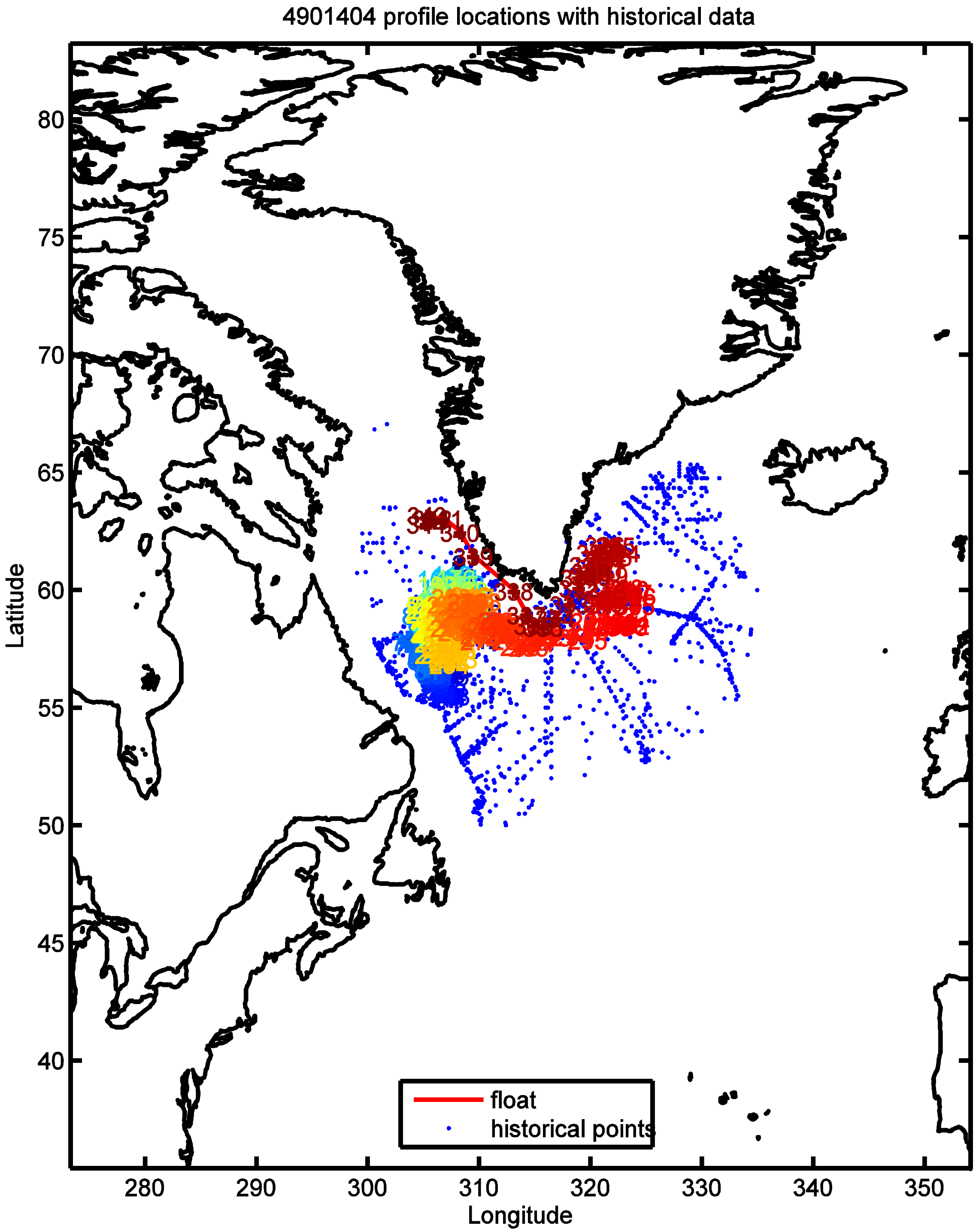


Figure F5a. APEX s/n 5264 / WMO #4901404.

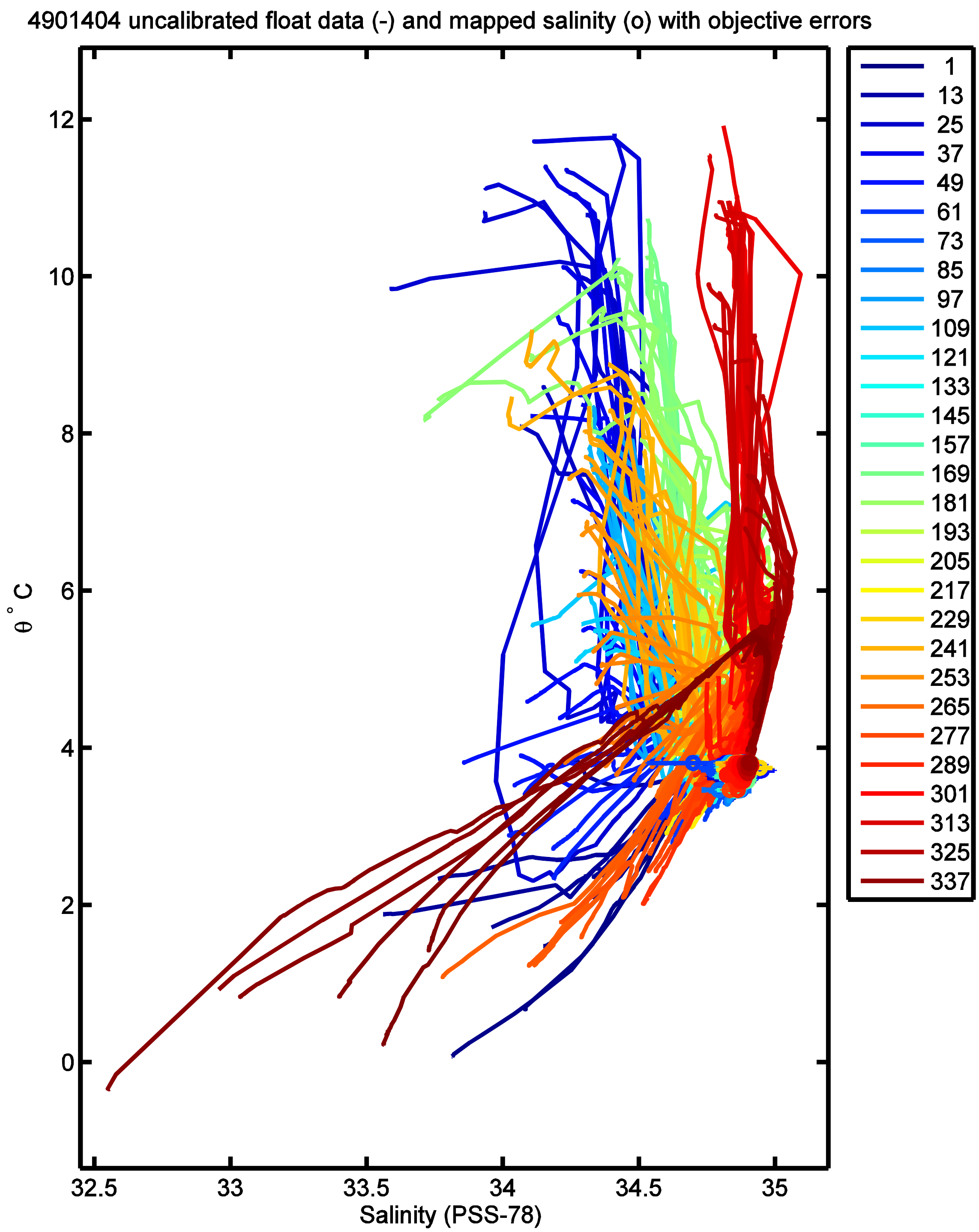


Figure F5b. APEX s/n 5264 / WMO #4901404.

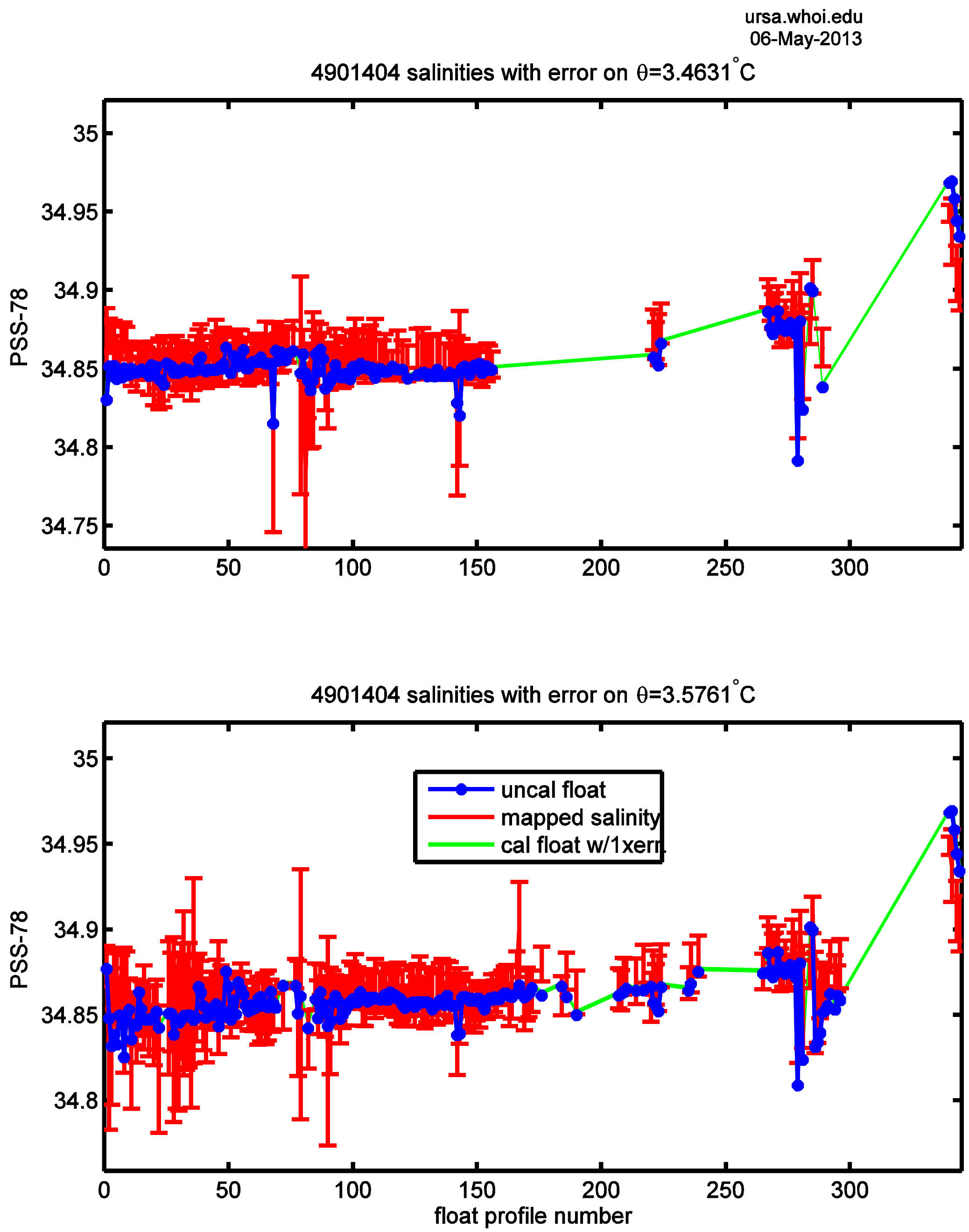
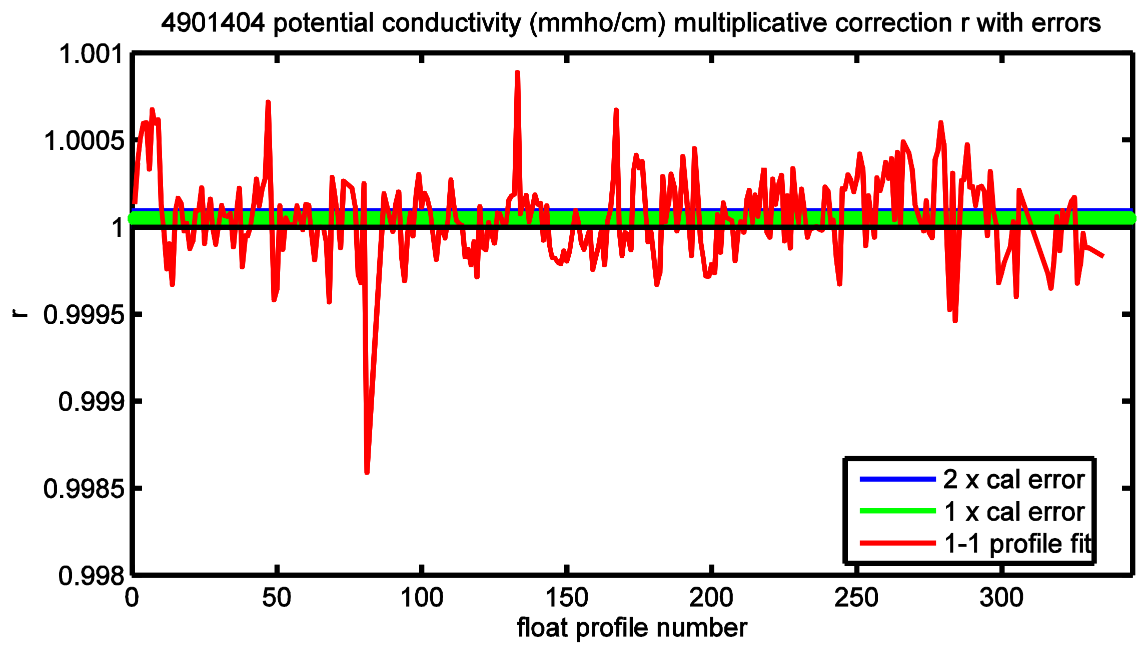


Figure F5c. APEX s/n 5264 / WMO #4901404.



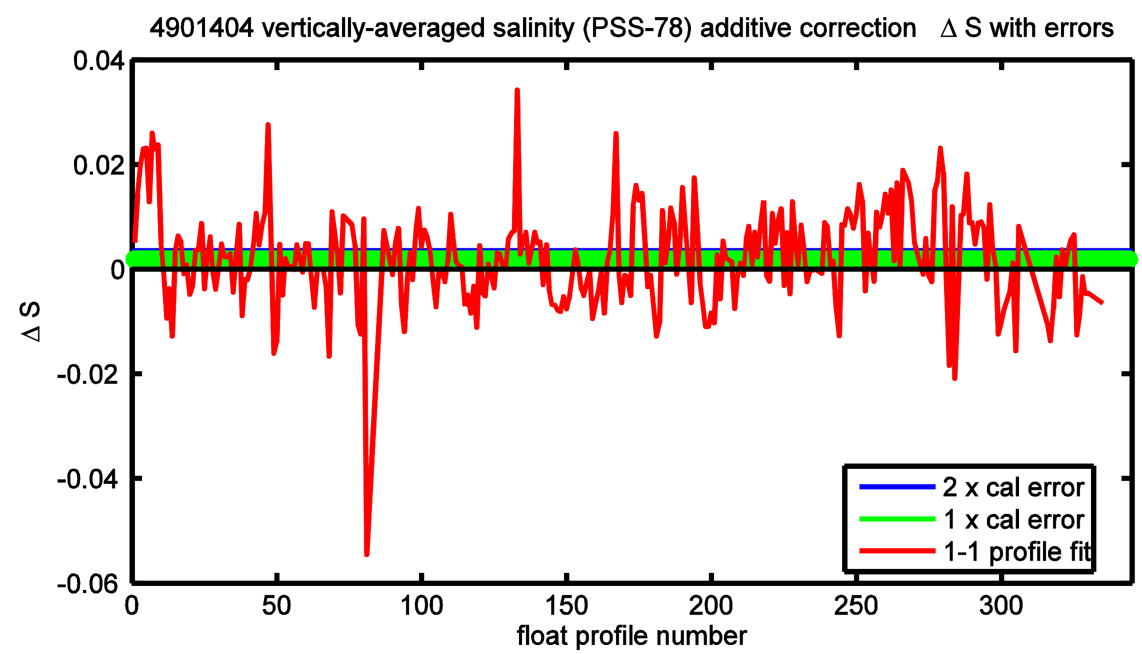


Figure F5d. APEX s/n 5264 / WMO #4901404.

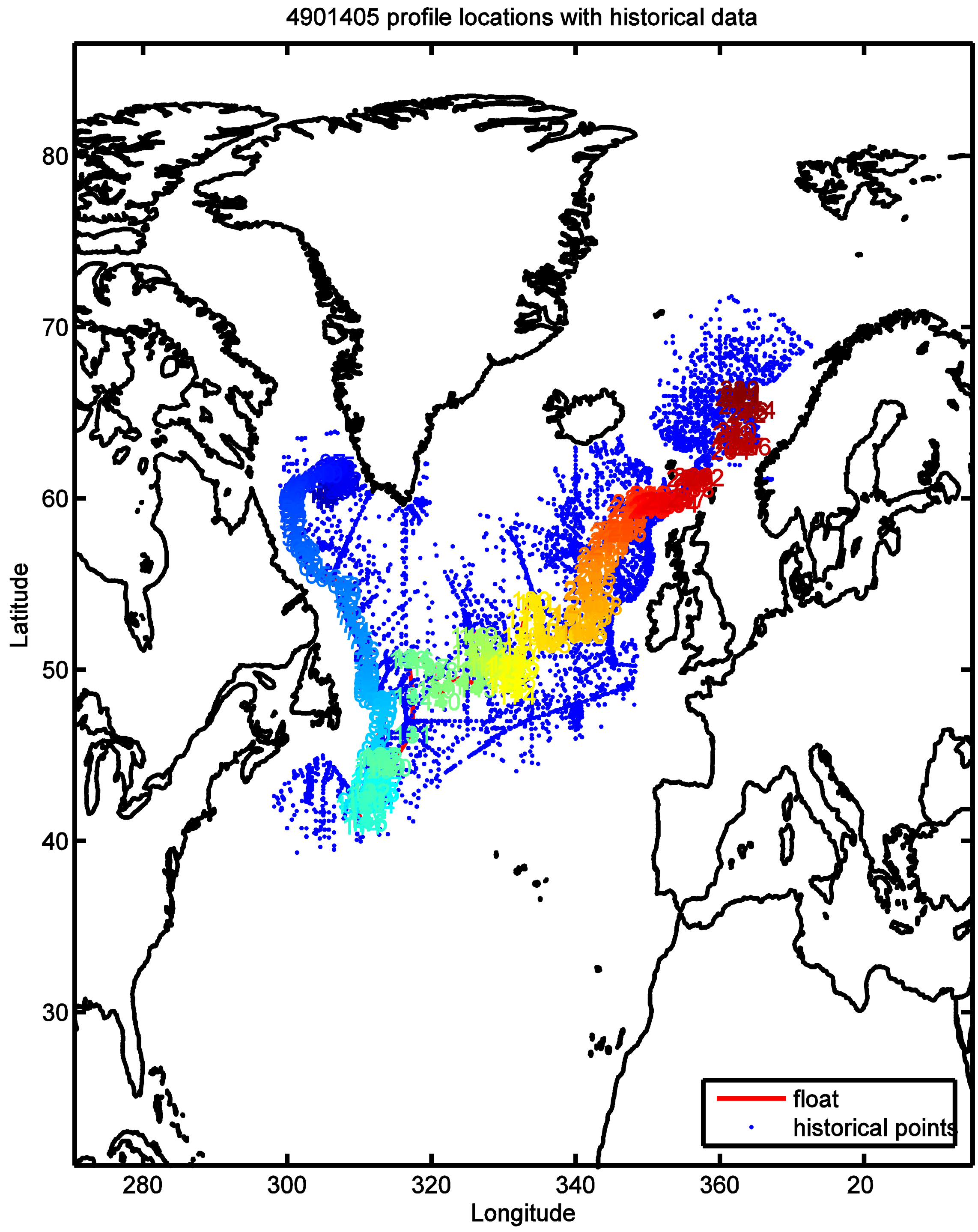


Figure F6a. APEX s/n 5265 / WMO #4901405.

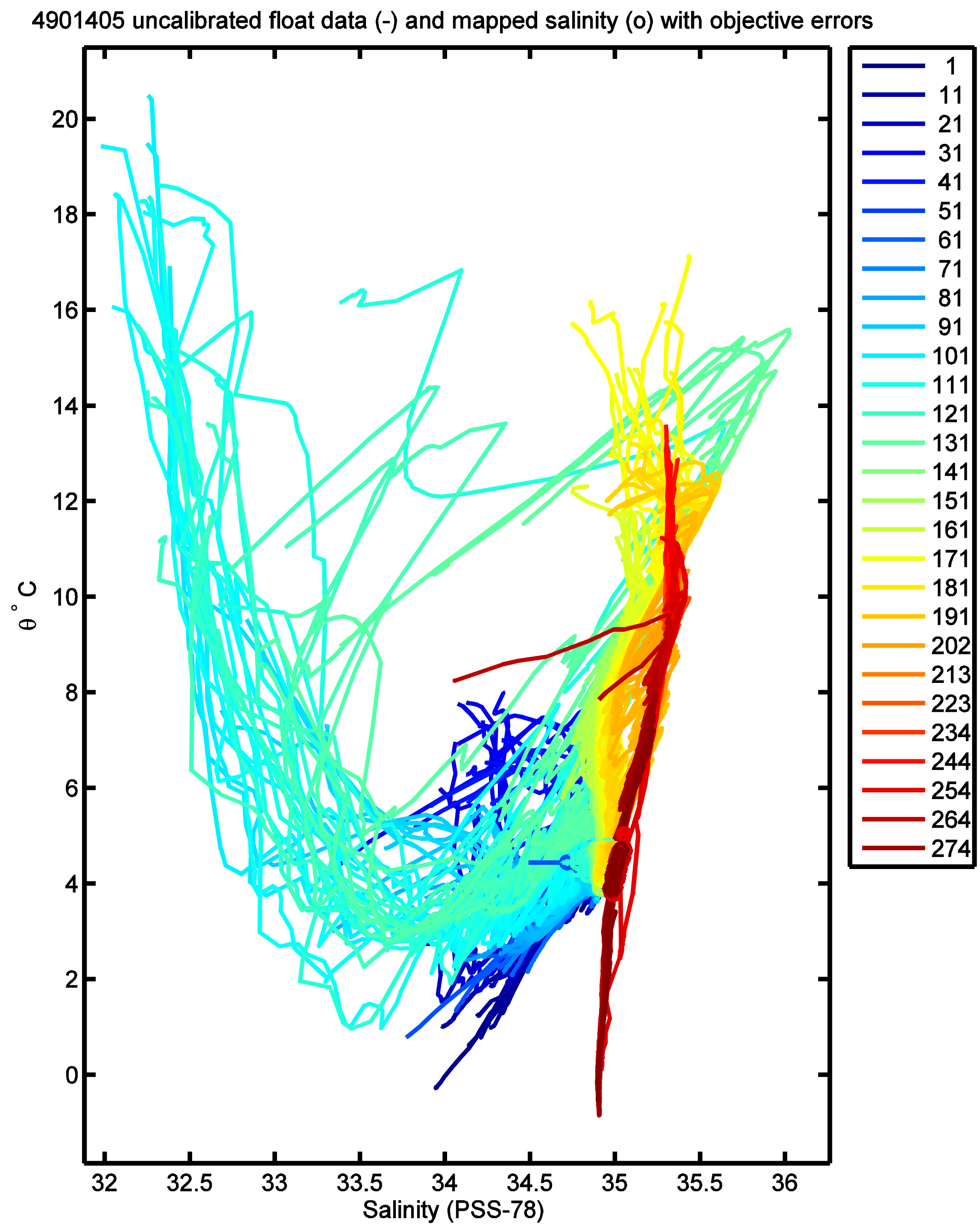


Figure F6b. APEX s/n 5265 / WMO #4901405.

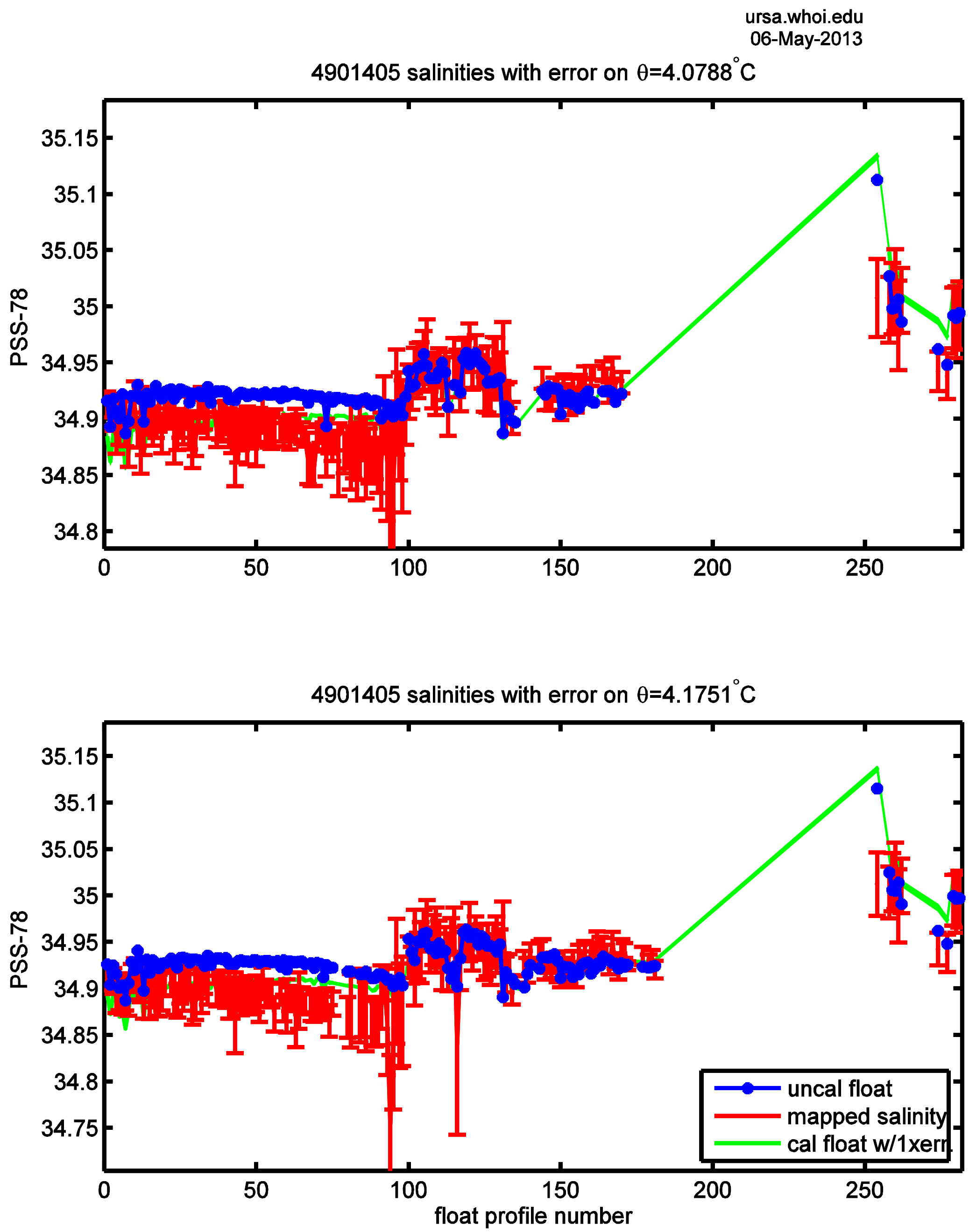


Figure F6c. APEX s/n 5265 / WMO #4901405.

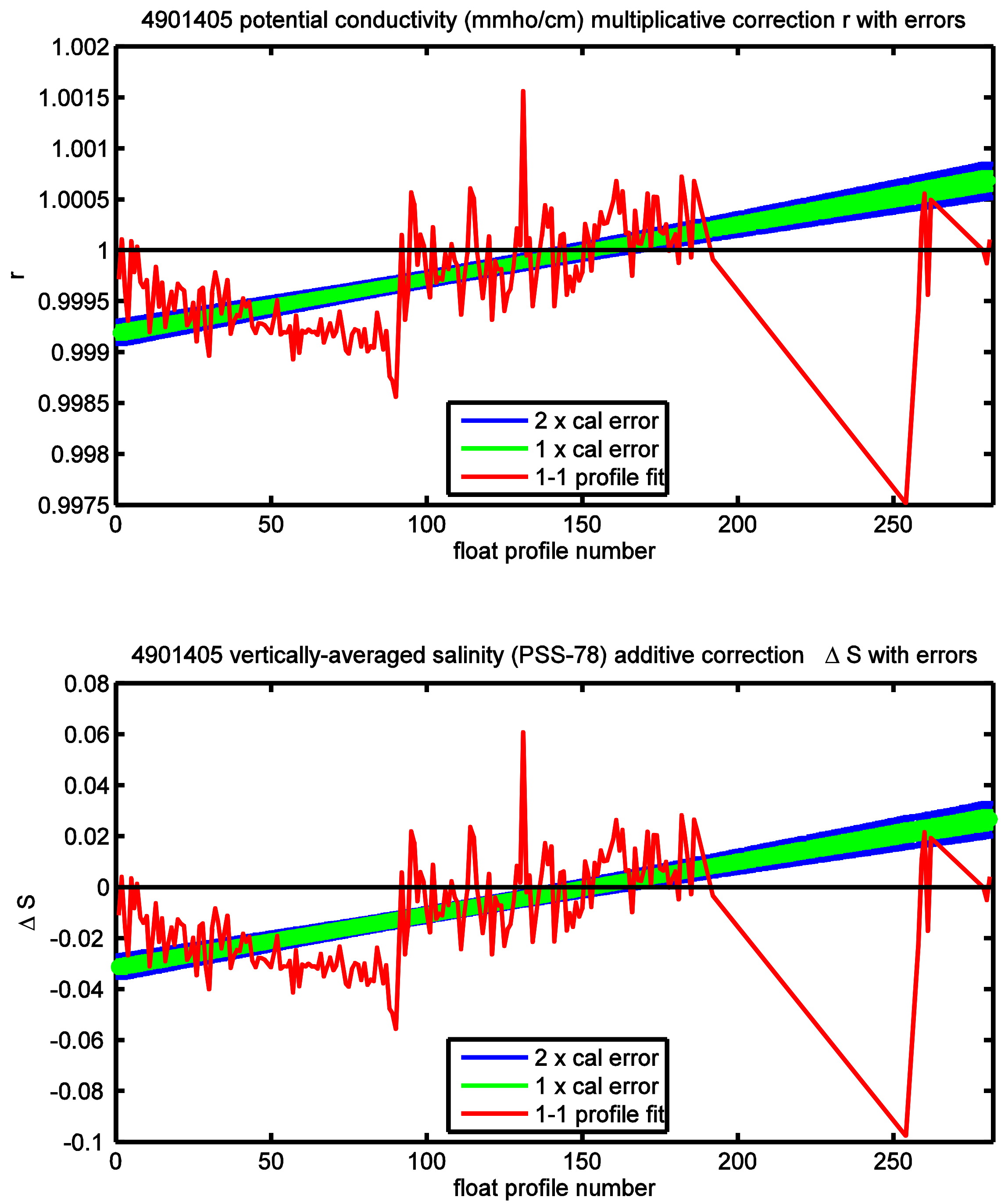


Figure F6d. APEX s/n 5265 / WMO #4901405.

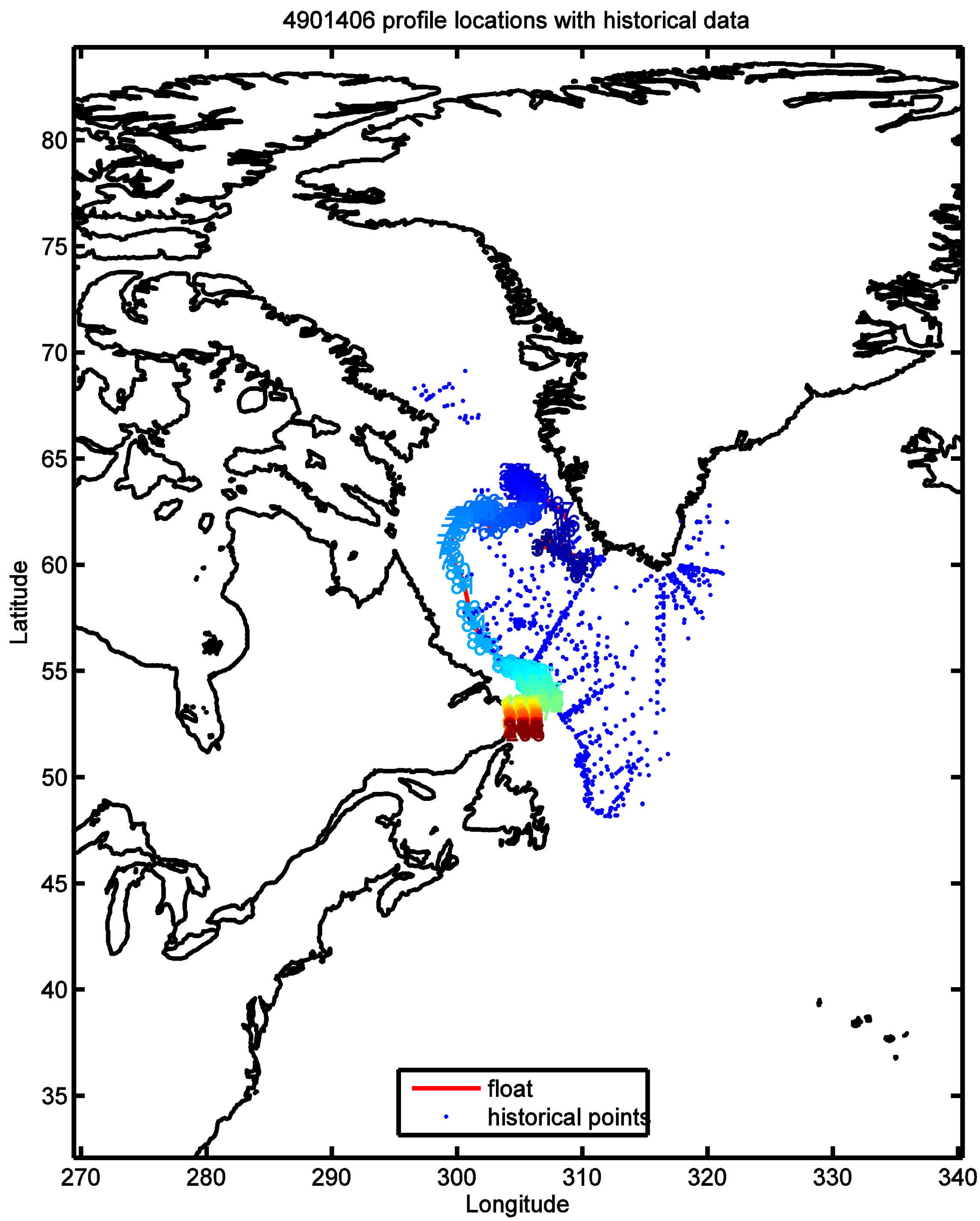


Figure F7a. APEX s/n 5266 / WMO #4901406.

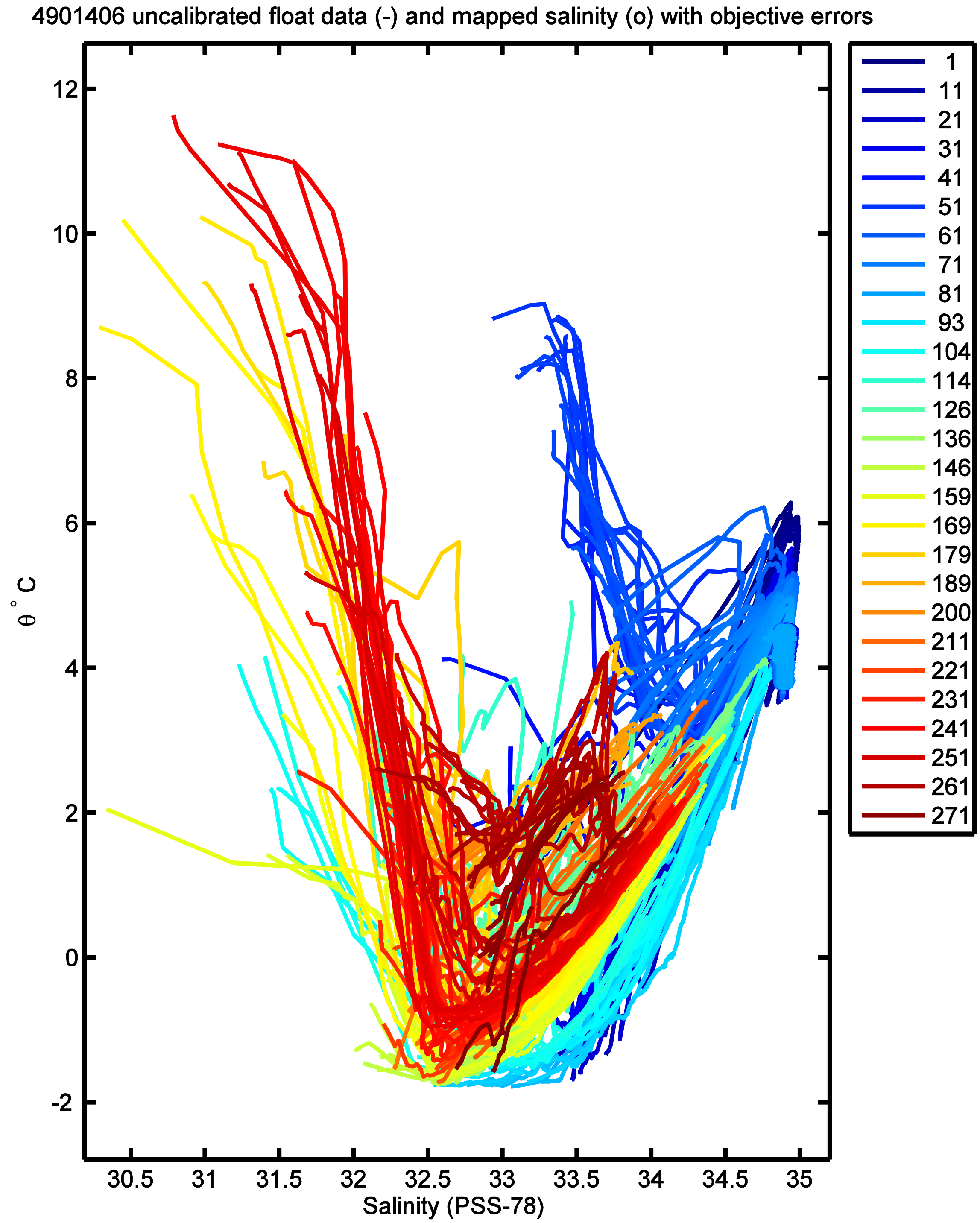


Figure F7b. APEX s/n 5266 / WMO #4901406.

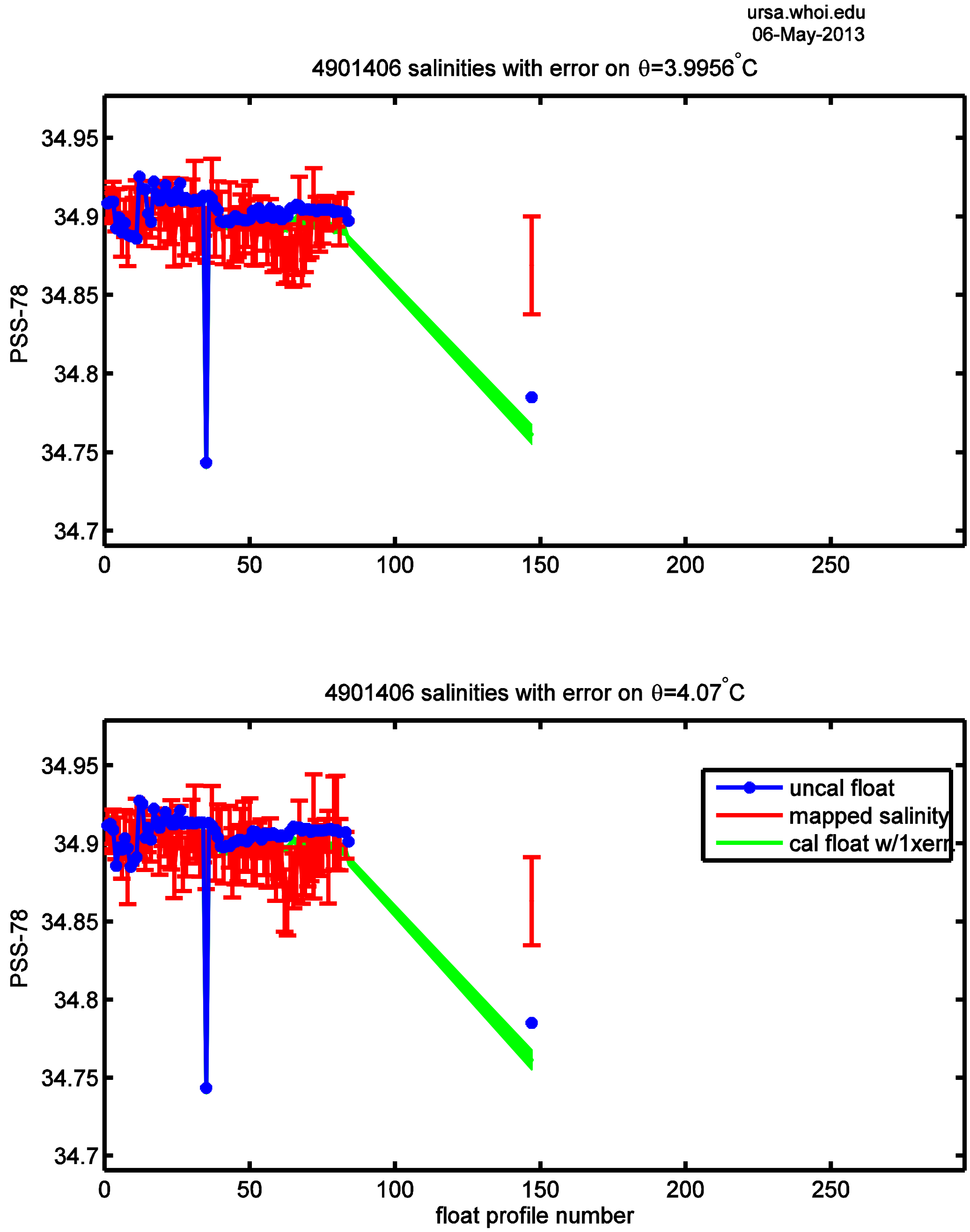


Figure F7c. APEX s/n 5266 / WMO #4901406.

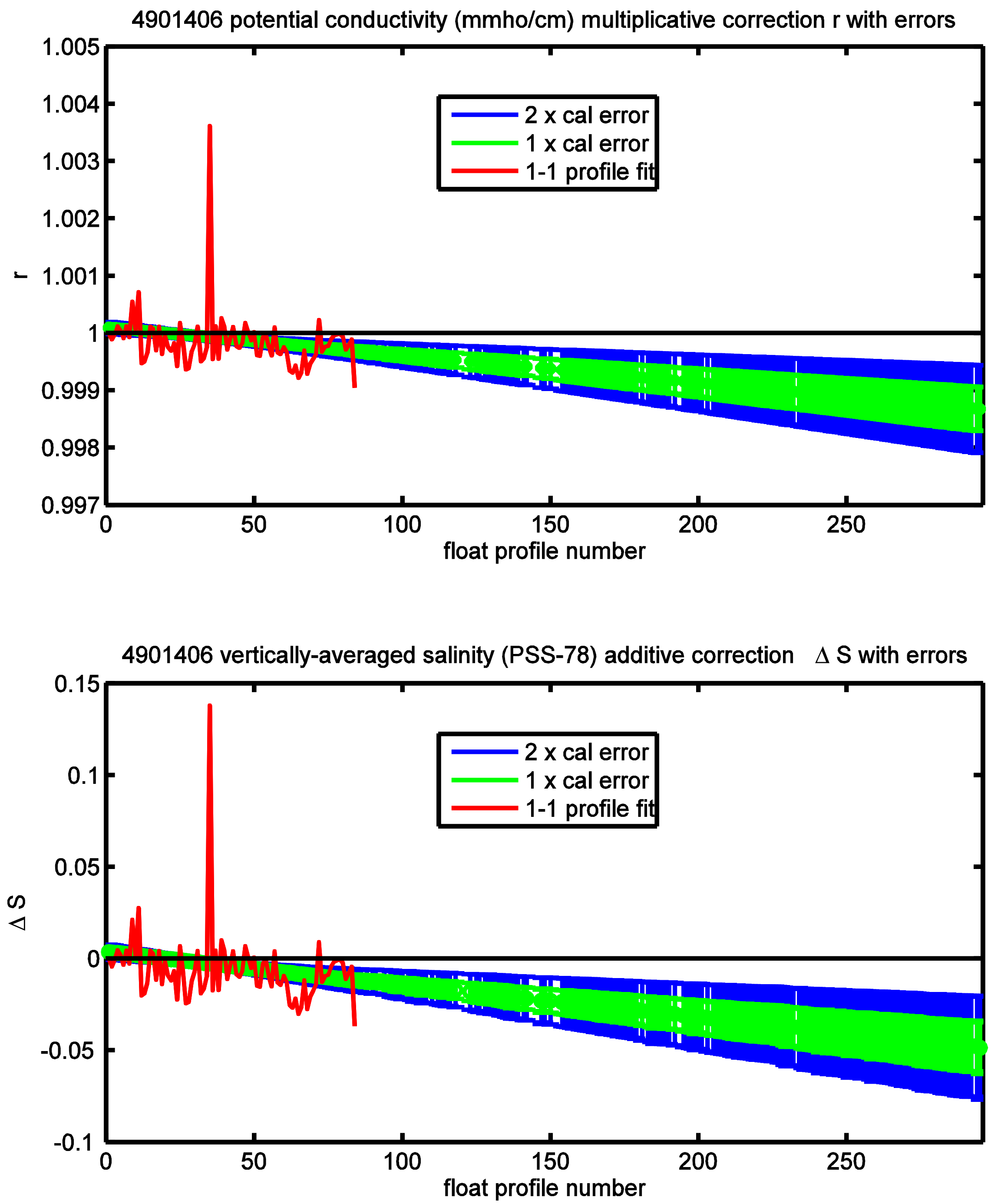


Figure F7d. APEX s/n 5266 / WMO #4901406.

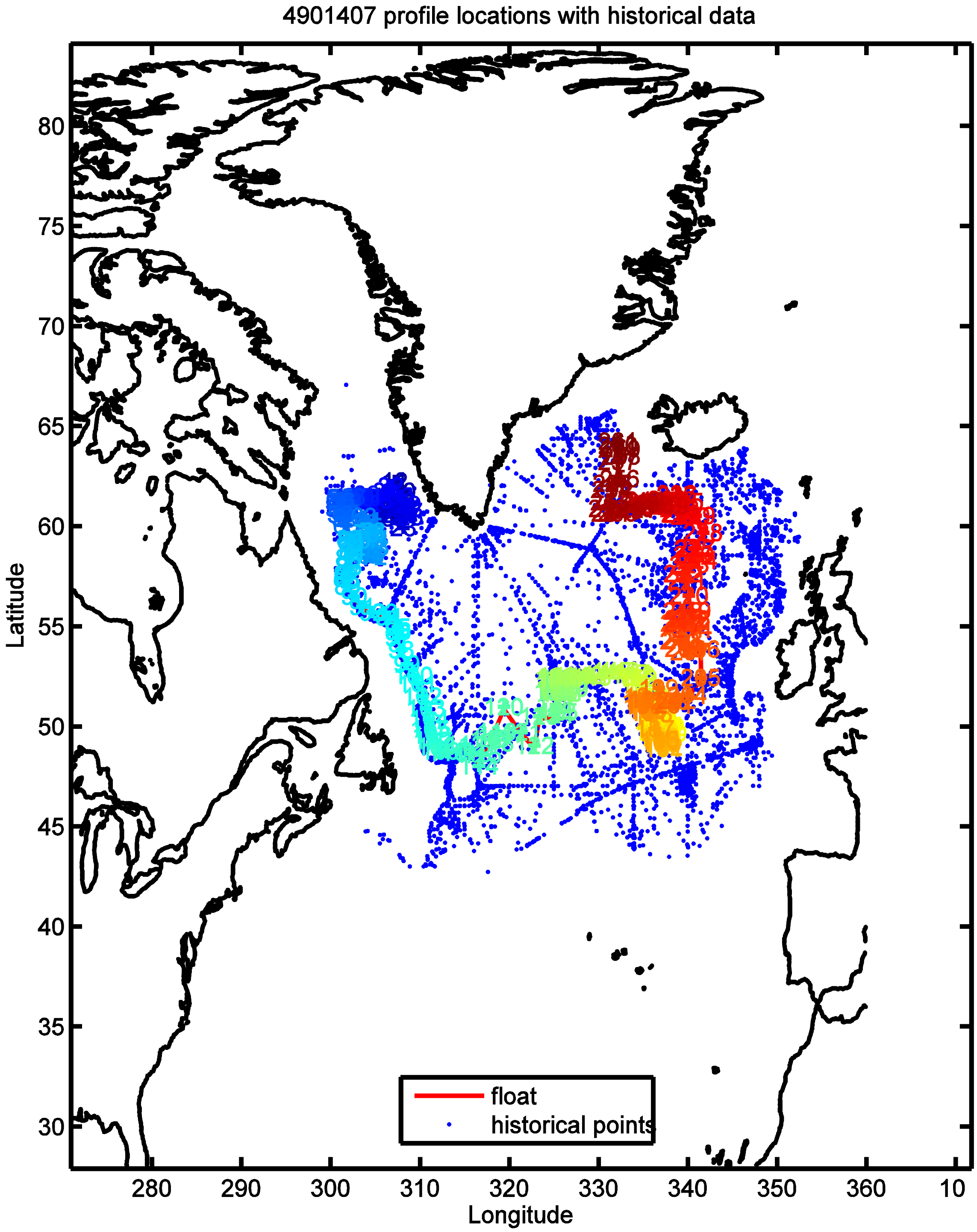


Figure F8a. APEX s/n 5267 / WMO #4901407.

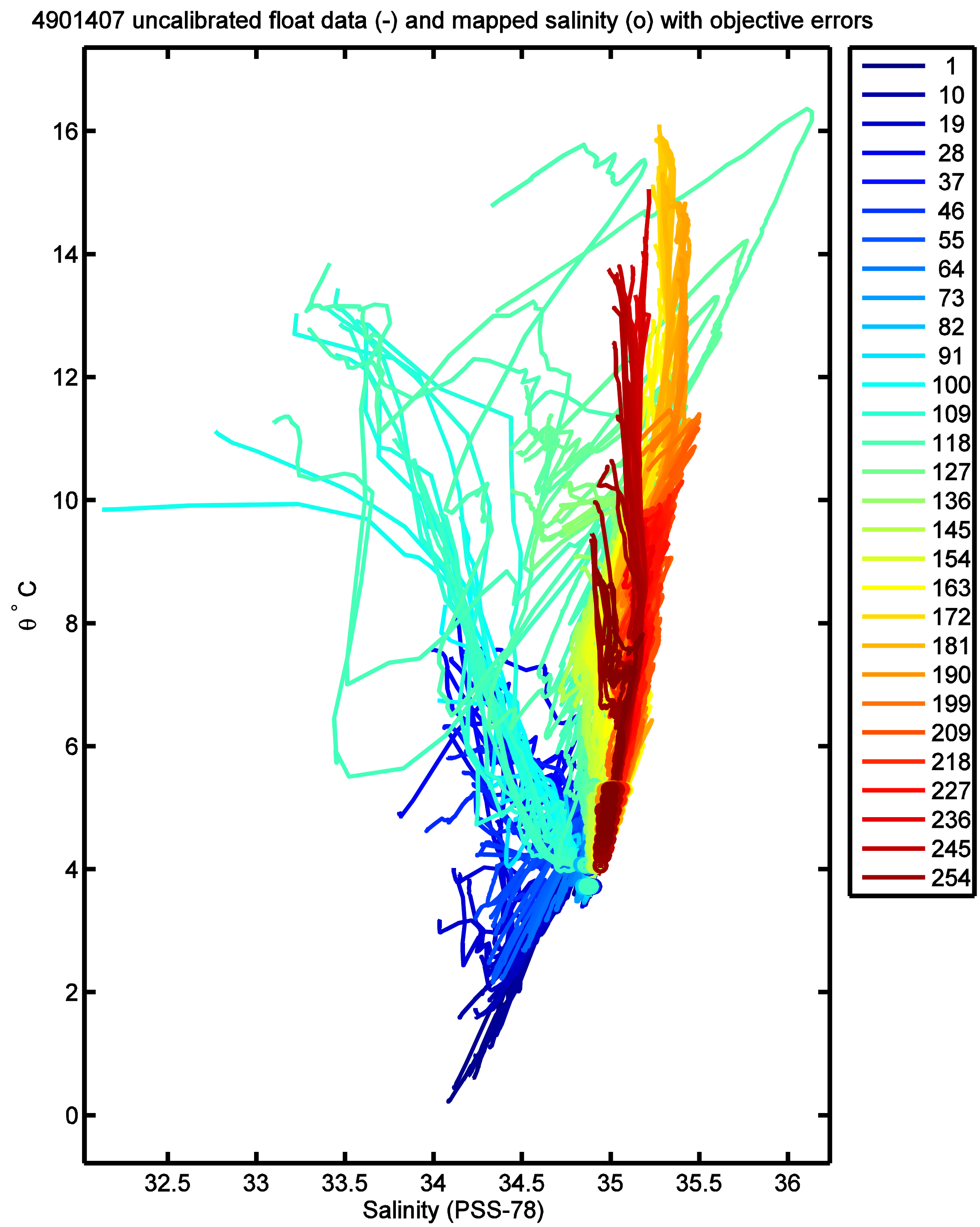


Figure F8b. APEX s/n 5267 / WMO #4901407.

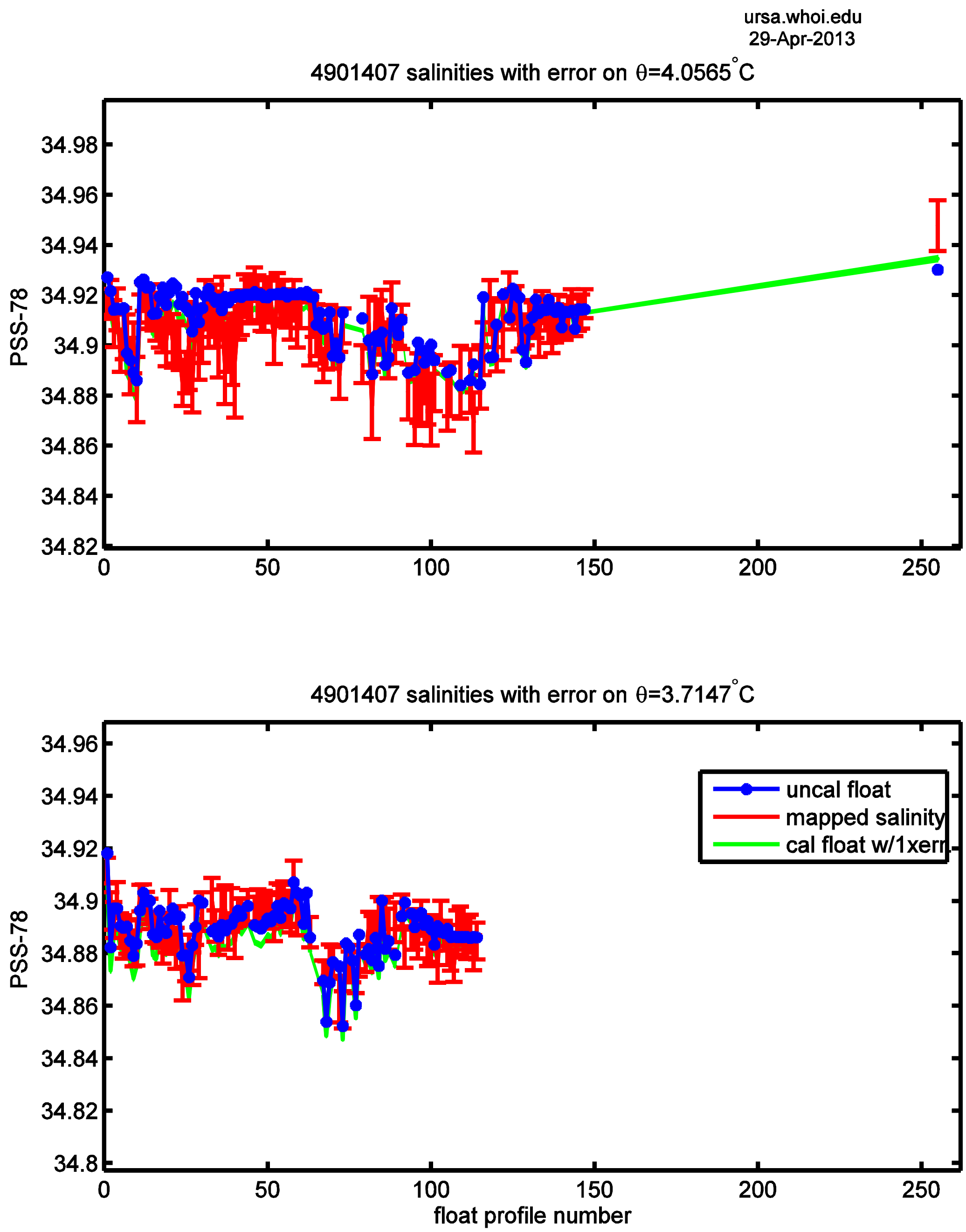
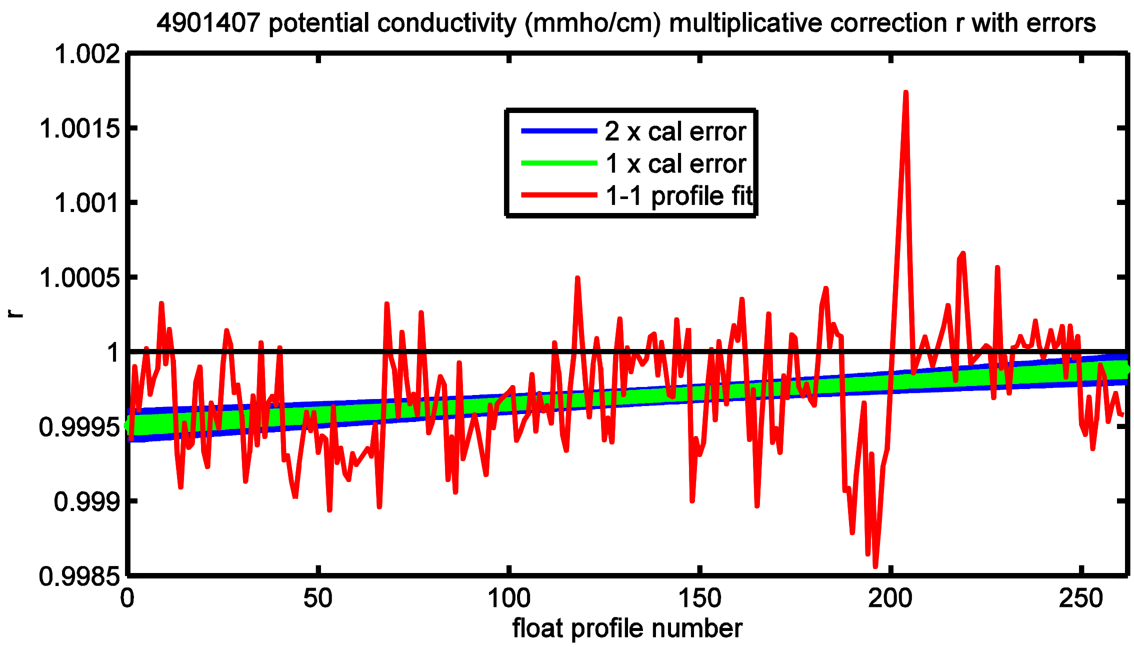


Figure F8c. APEX s/n 5267 / WMO #4901407.



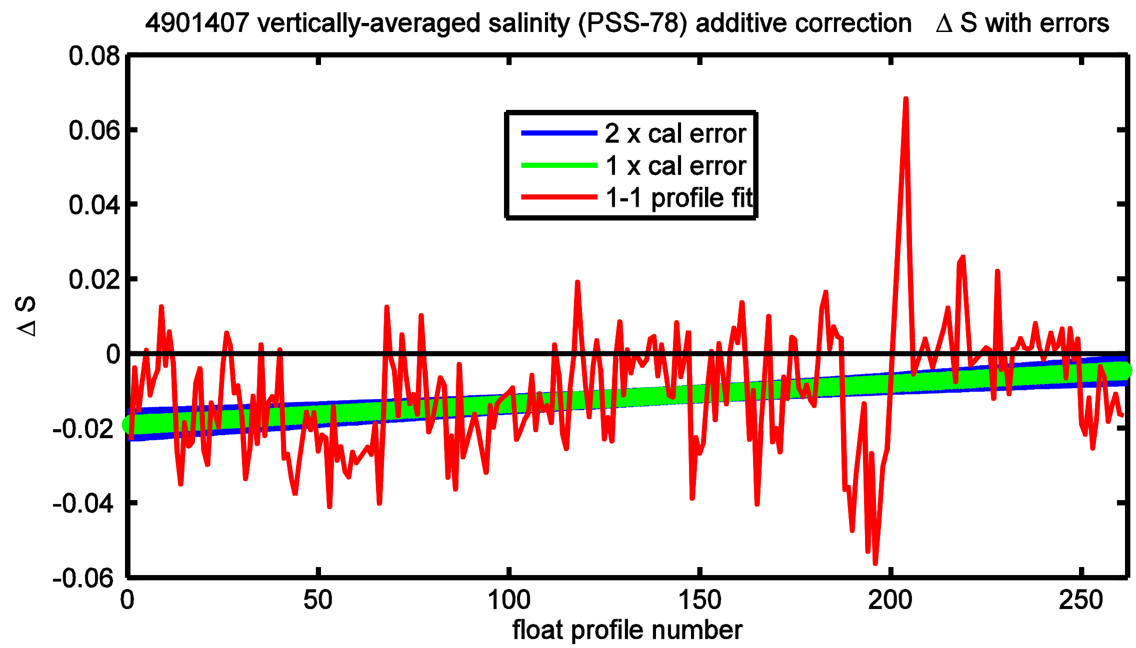


Figure F8d. APEX s/n 5267 / WMO #4901407.

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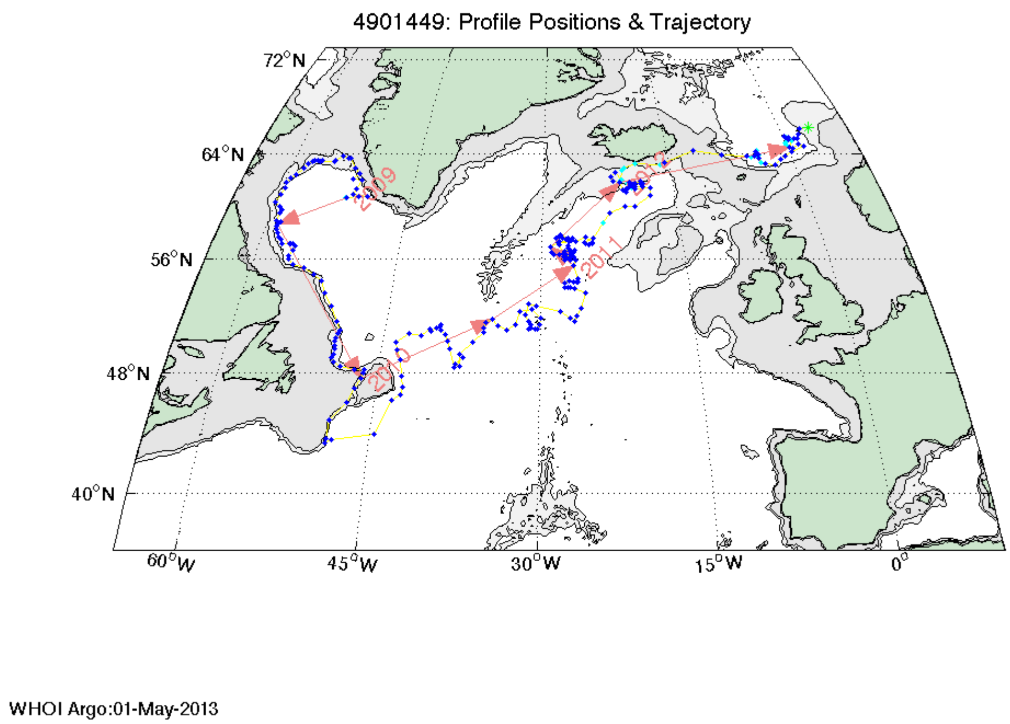

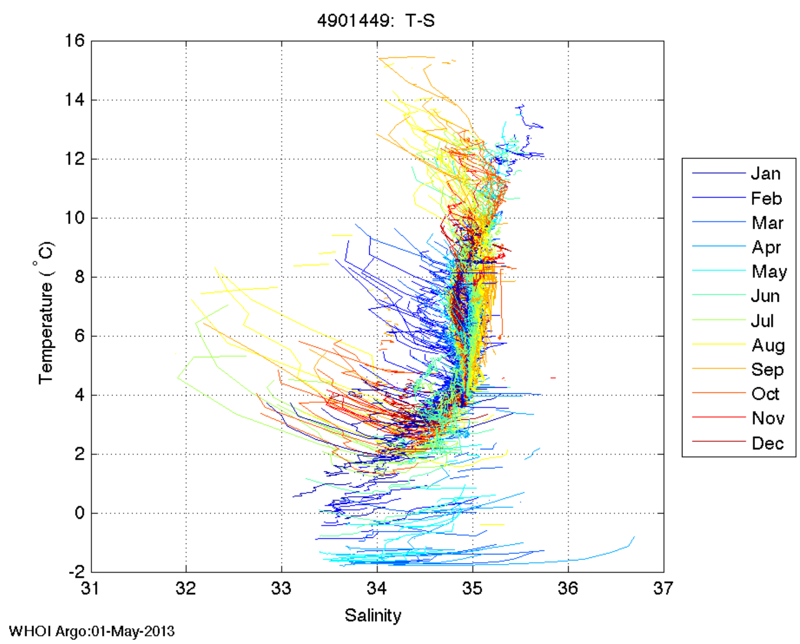

Figure 9. (top) APEX trajectory. (bottom) T-S diagram, showing bad salinity data. This float had no salvageable salinity, so suite of four plots shown for other floats not available.

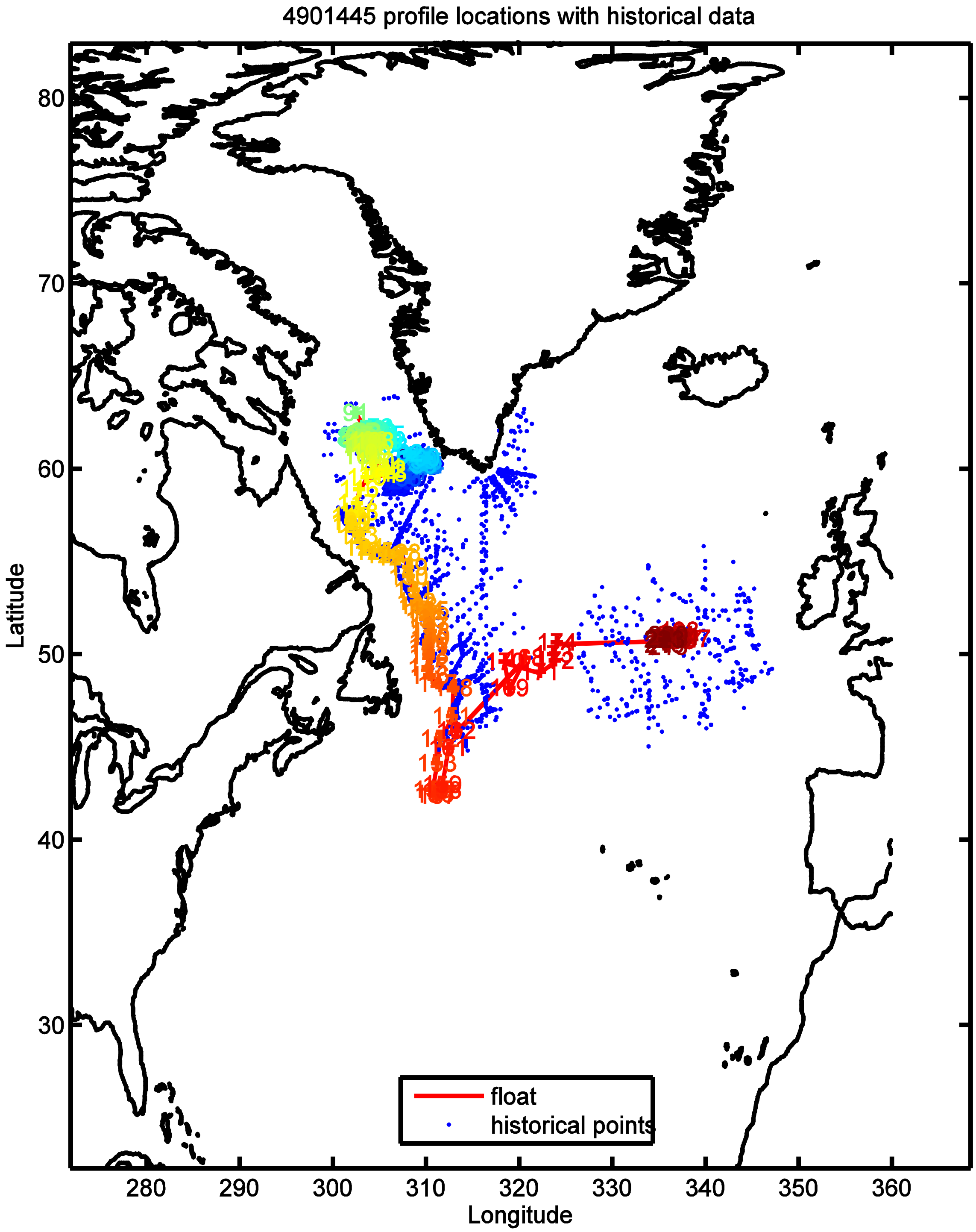

Figure F10a. APEX s/n 5270 / WMO #4901445.

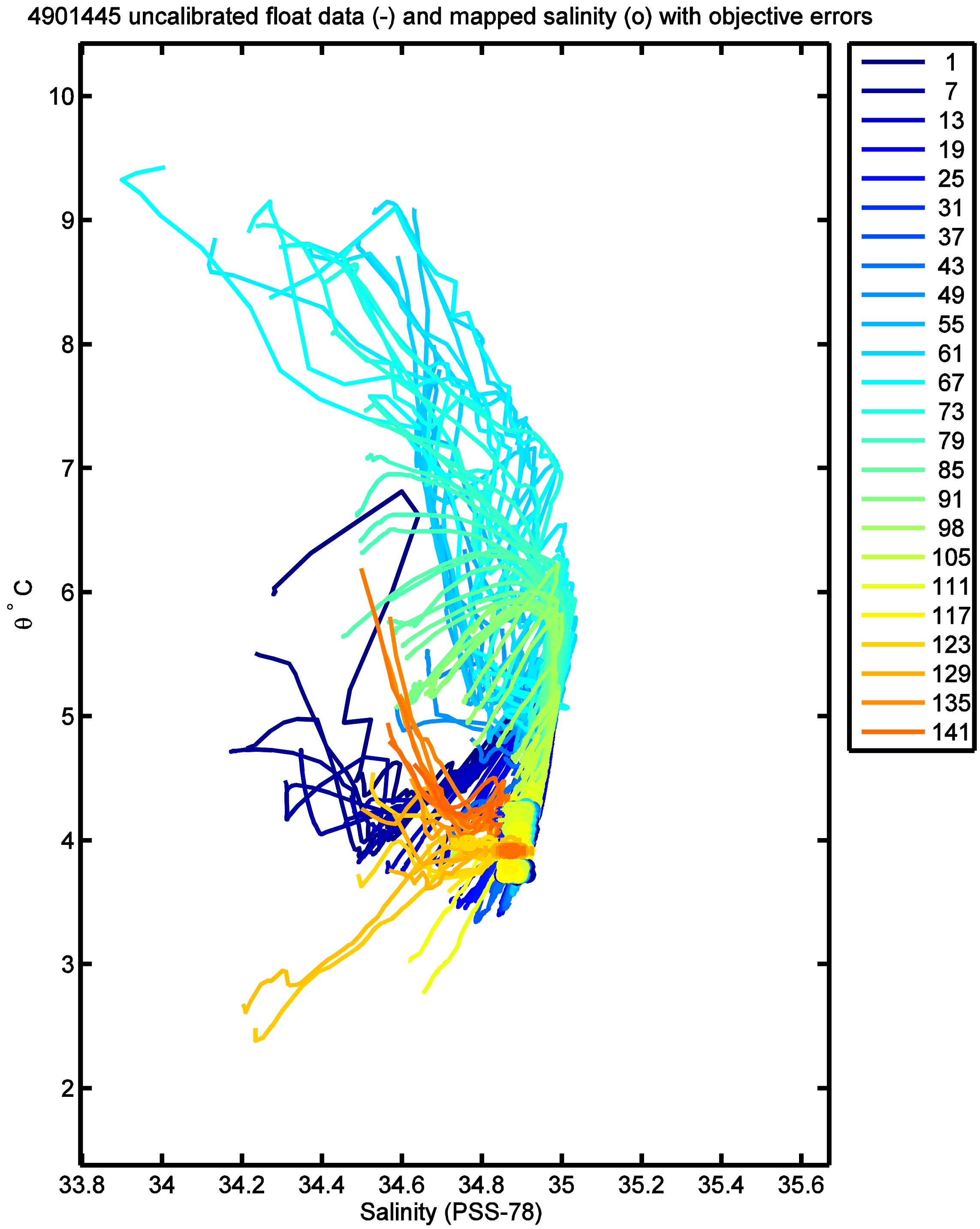

Figure F9b. APEX s/n 5270 / WMO #4901445.

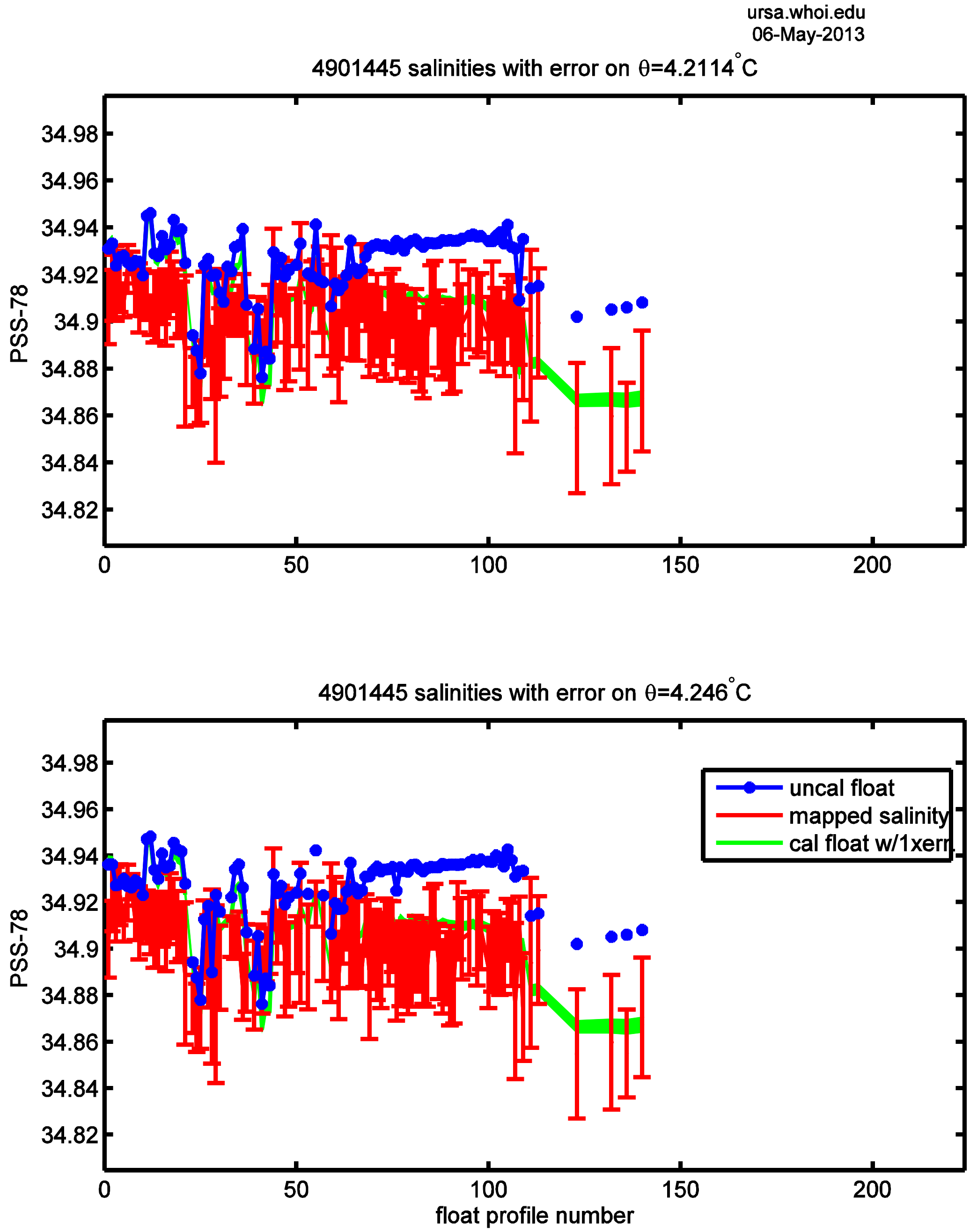

Figure F9c. APEX s/n 5270 / WMO #4901445.

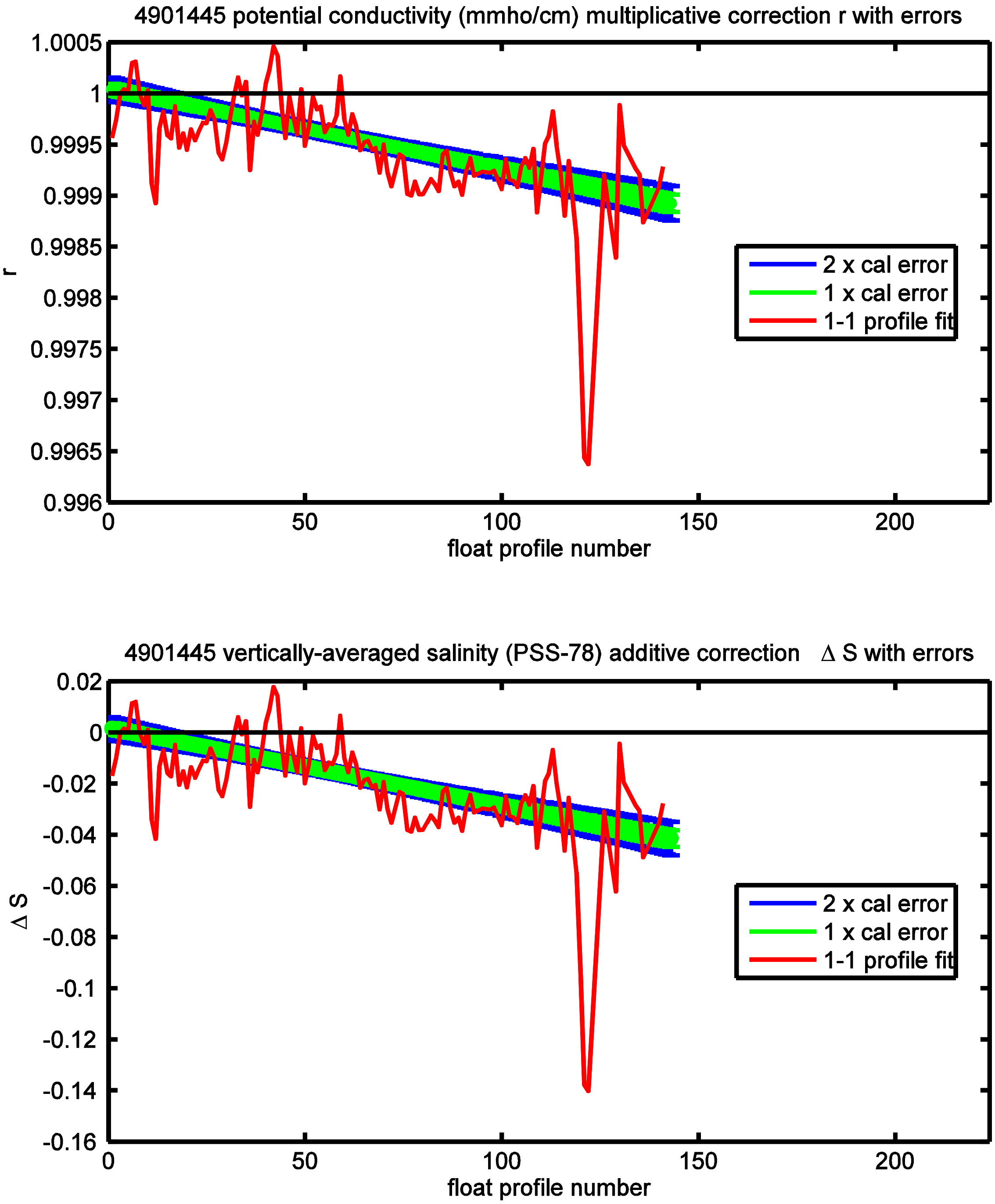

Figure F9d. APEX s/n 5270 / WMO #4901445.

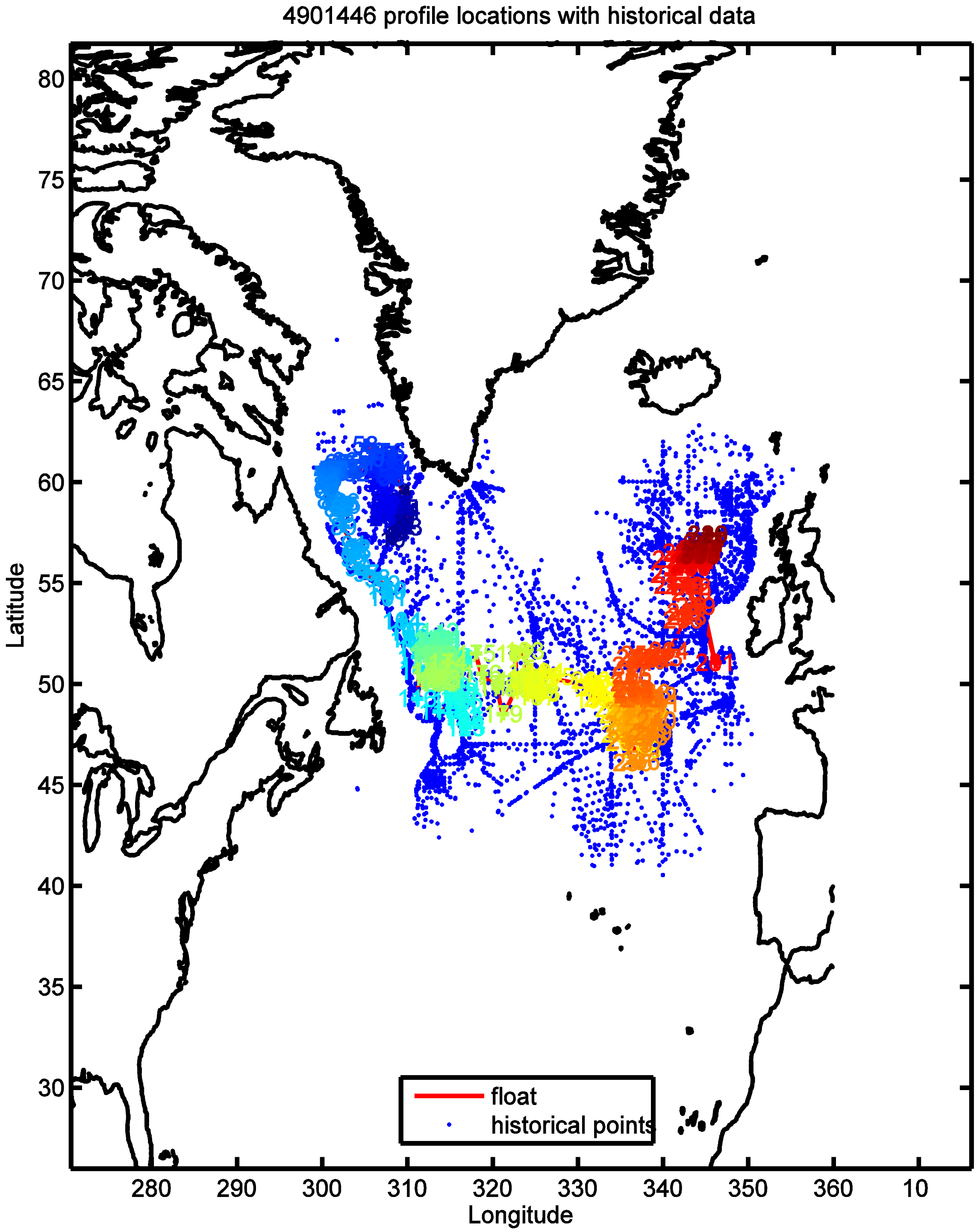

Figure F10a. APEX s/n 5271 / WMO #4901446.

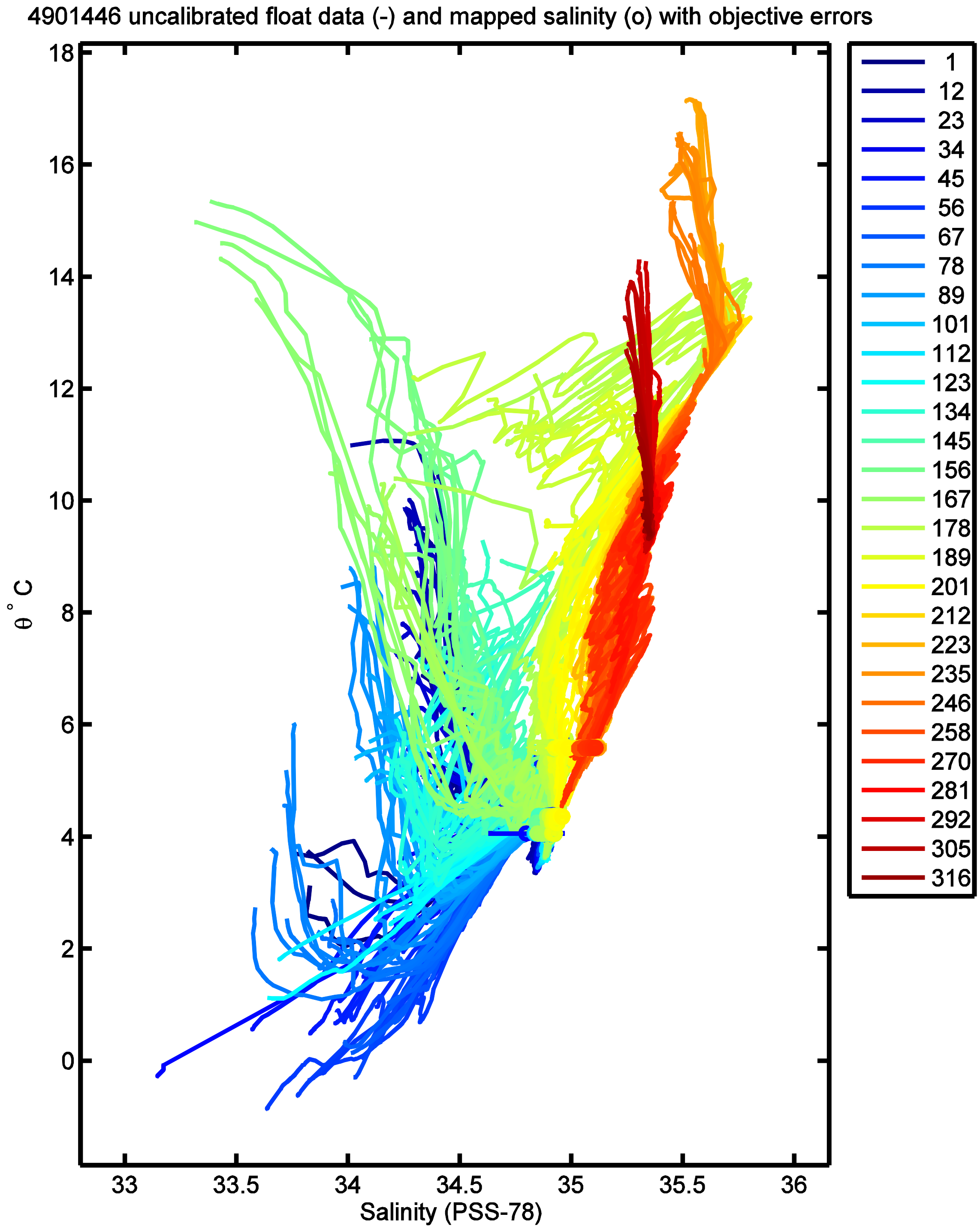

Figure F10b. APEX s/n 5271 / WMO #4901446.

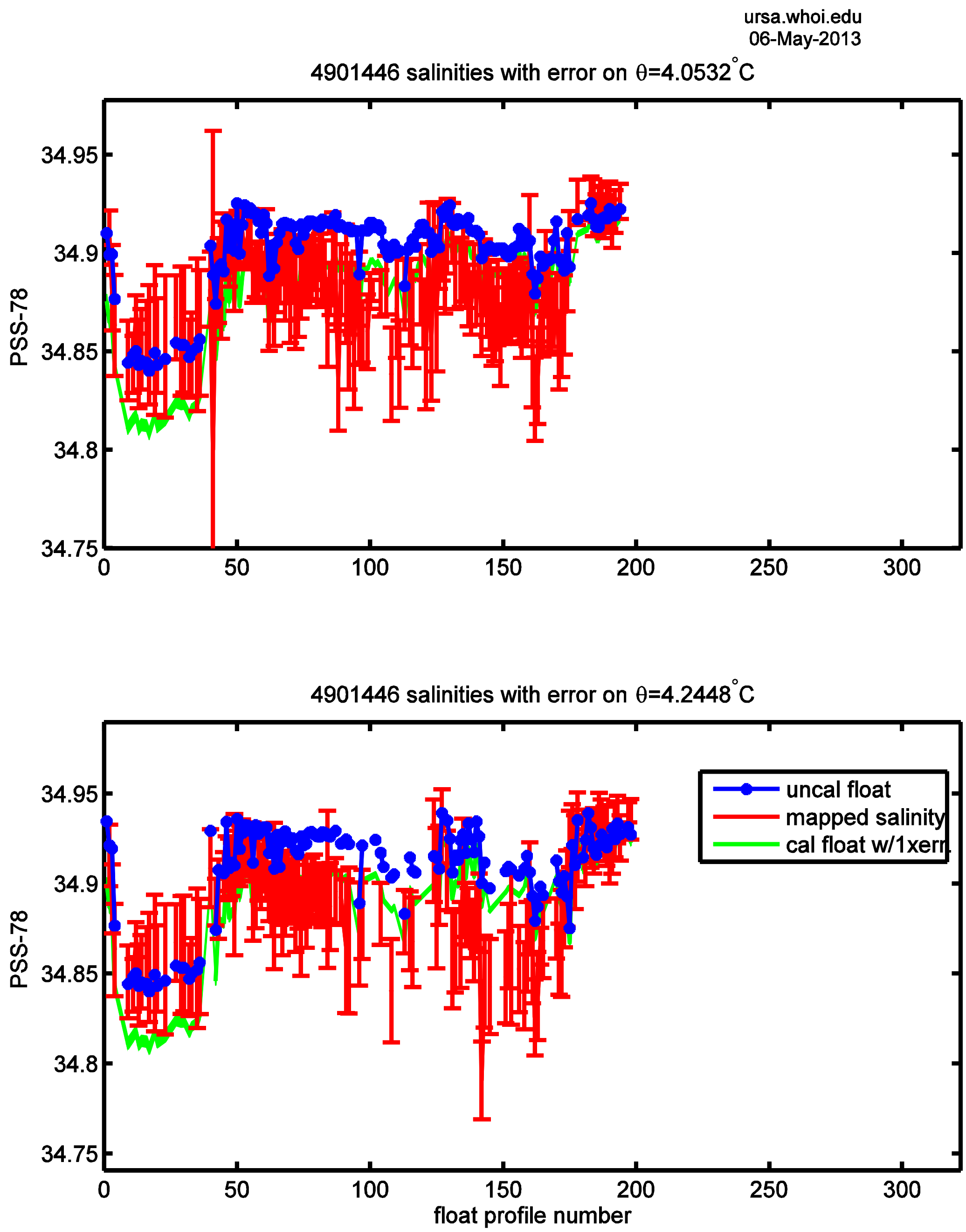

Figure F11c. APEX s/n 5271 / WMO #4901446.

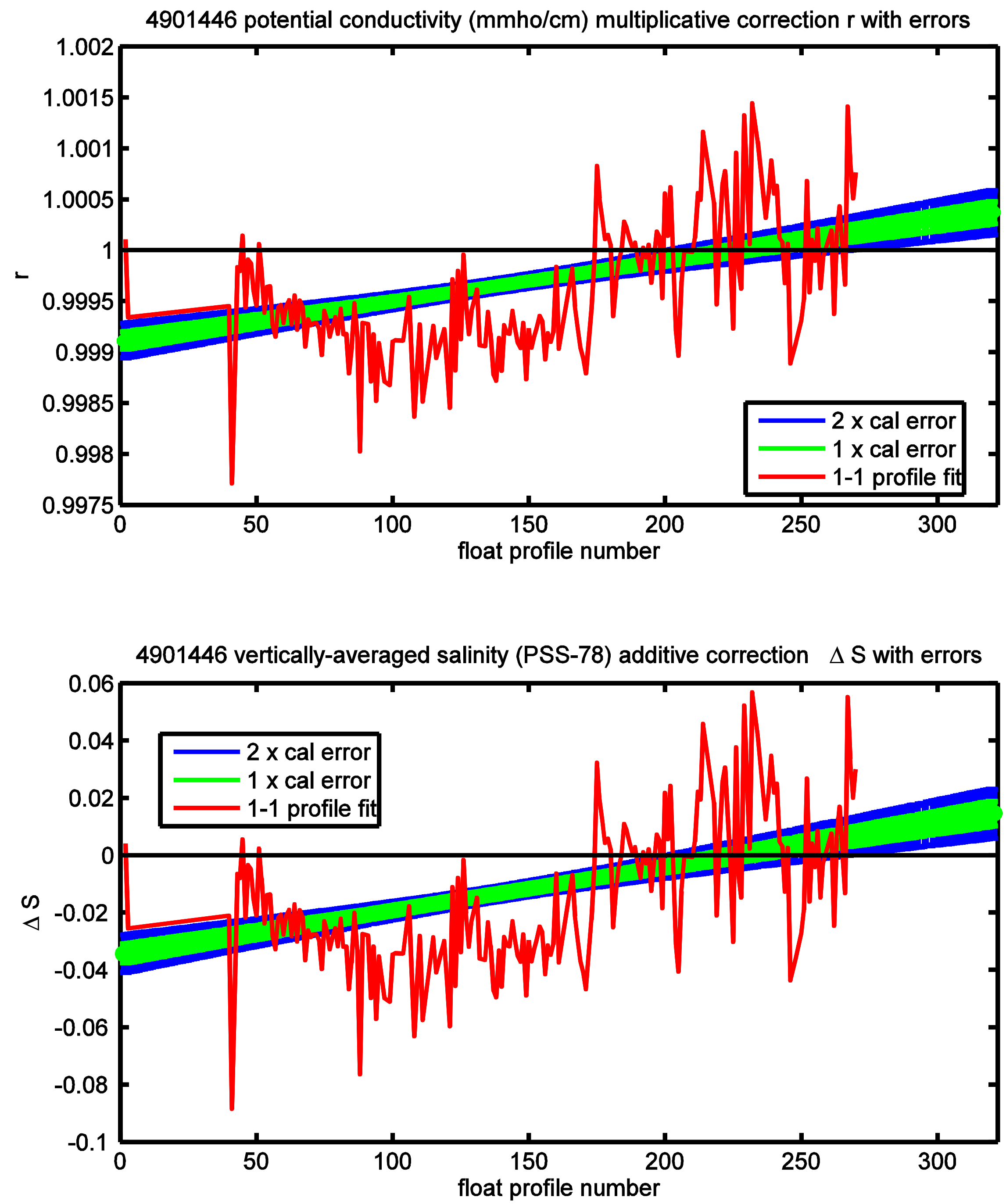

Figure F11d. APEX s/n 5271 / WMO #4901446.

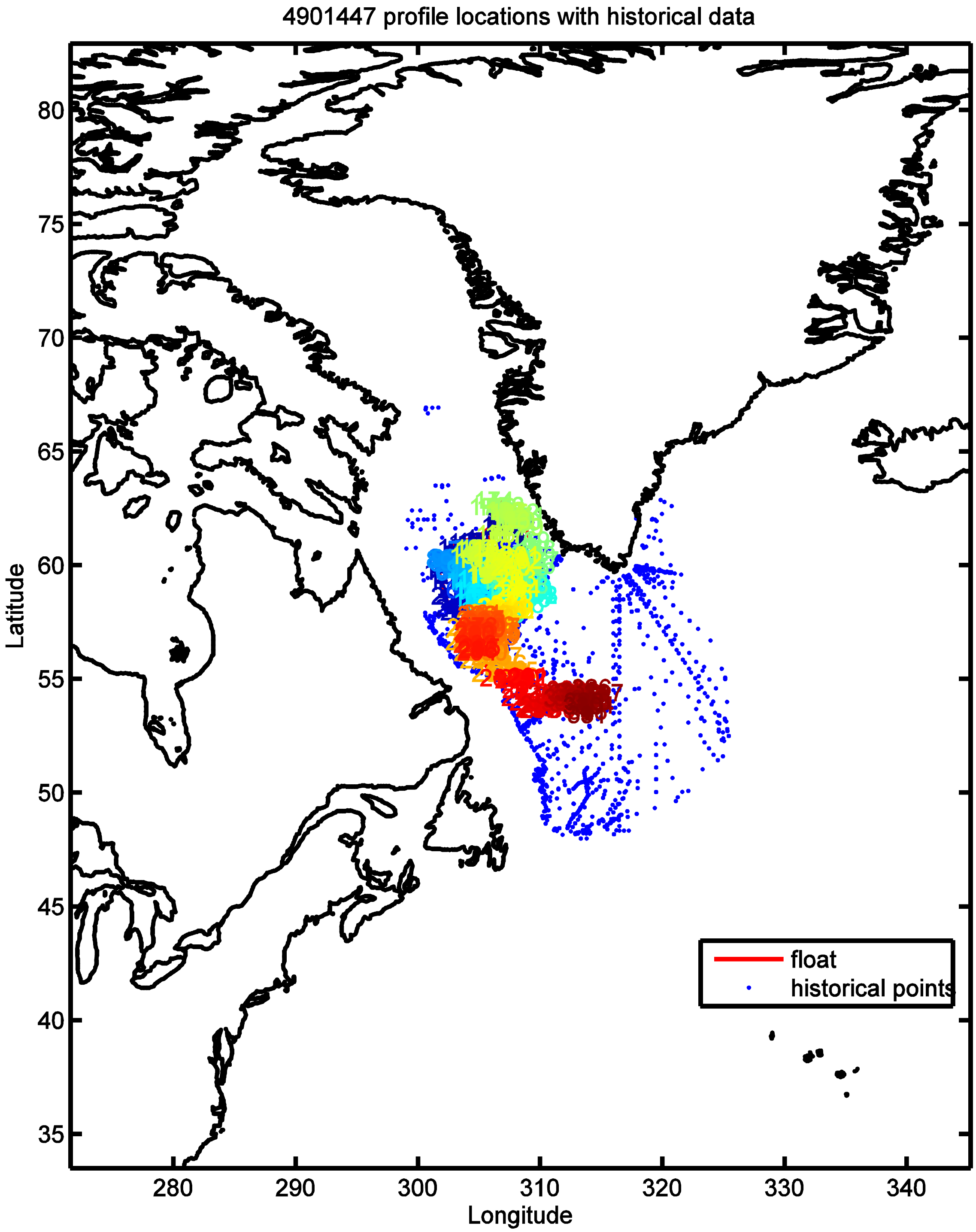

Figure F12a. APEX s/n 5272 / WMO #4901447.

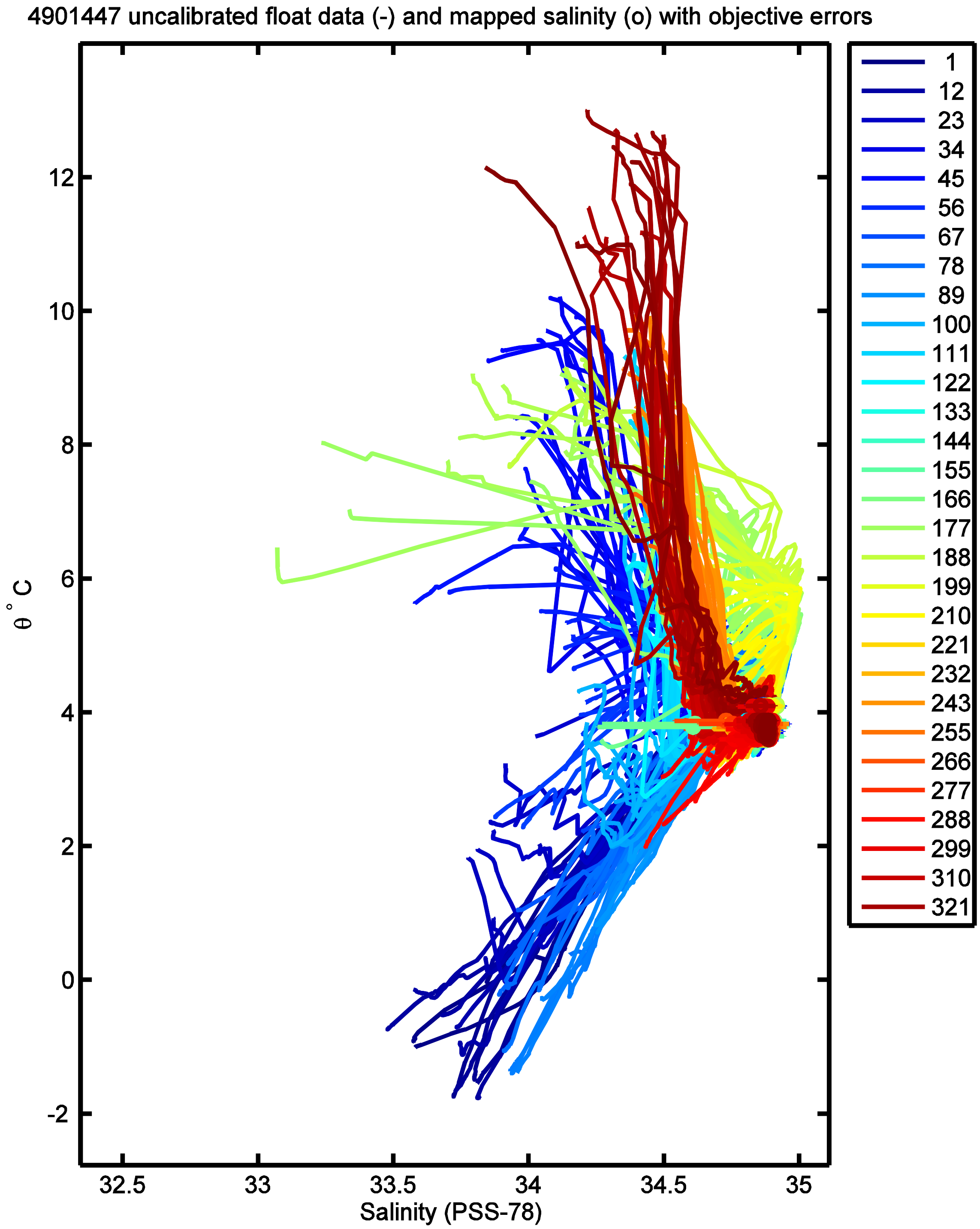

Figure F12b. APEX s/n 5272 / WMO #4901447.

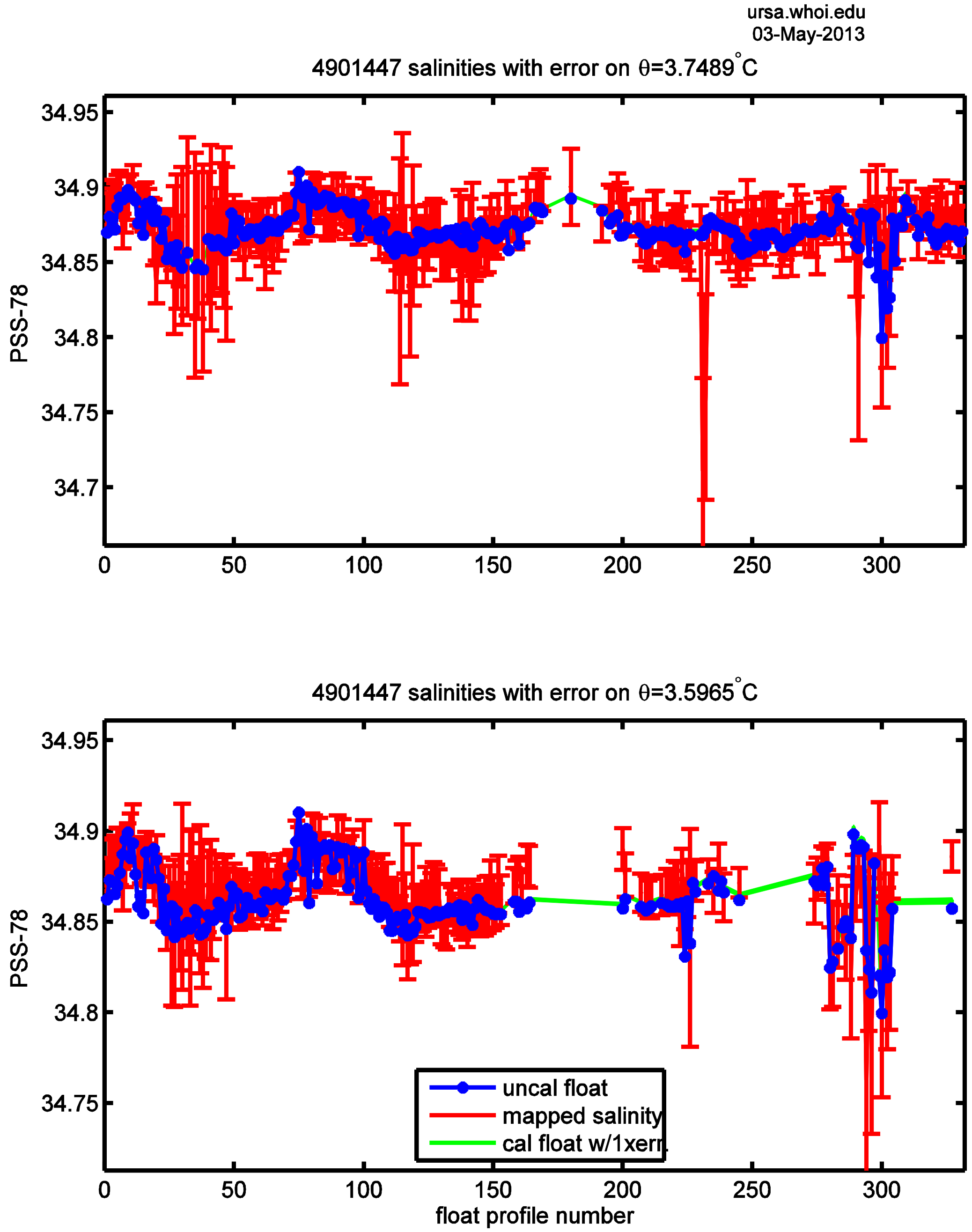

Figure F12c. APEX s/n 5272 / WMO #4901447.

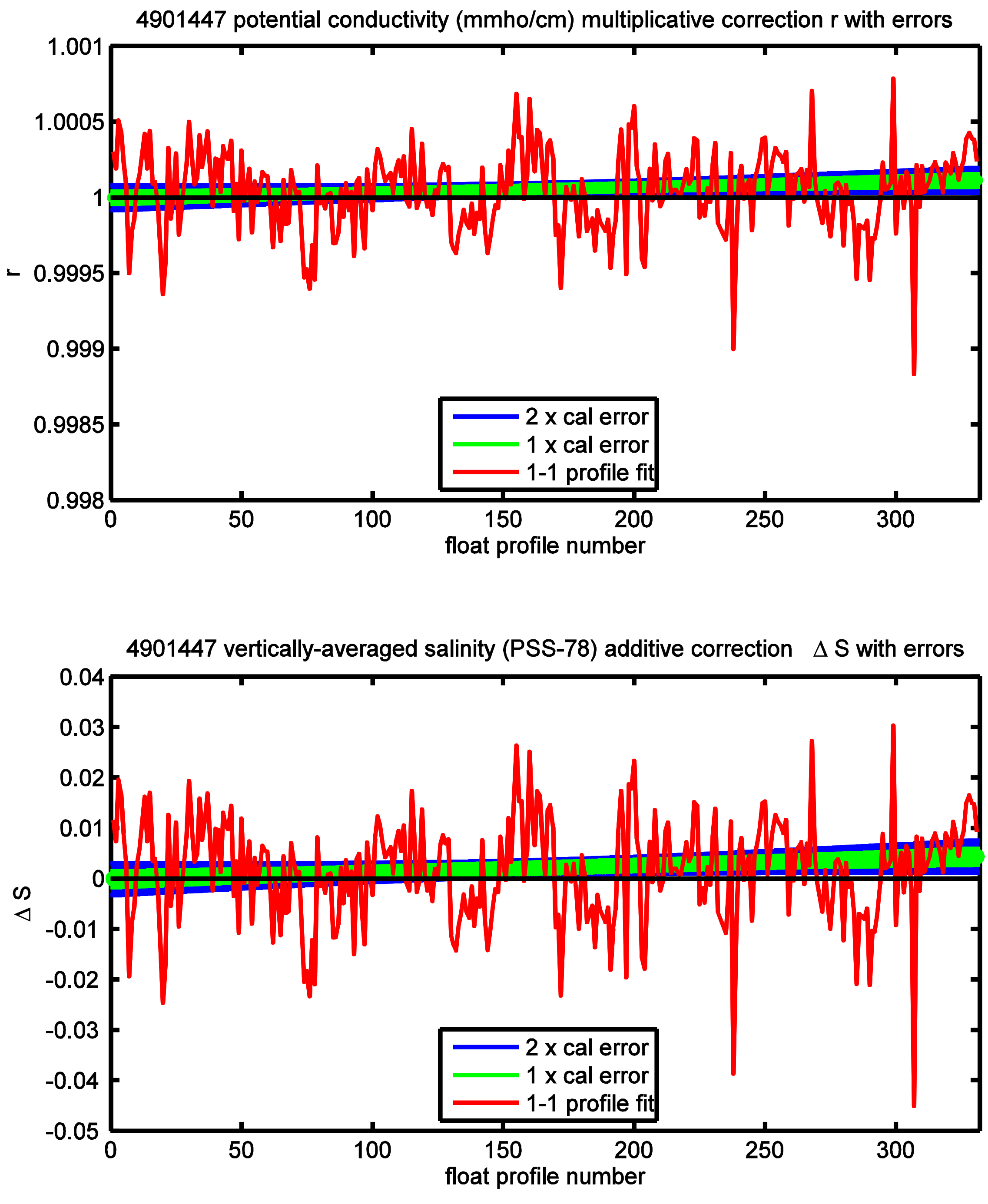

Figure F12d. APEX s/n 5272 / WMO #4901447.

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16. Abstract (Limit: 200 words)

This is the final data report of all hydrographic station, mooring, and subsurface float data collected by the Woods Hole Oceanographic Institution in 2007-2009 during the Impact of Irminger Rings on Deep Convection in the Labrador Sea experiment (IRINGS). The objectives of IRINGS were to (1) to determine the full water column hydrographic and velocity structure of newly-formed Irminger Rings that have entered the interior Labrador Sea; (2) to observe how Irminger Ring core properties are modified by atmospheric forcing over their lifetime; and (3) to improve the interpretation of sea surface height (SSH) anomalies in terms of newly formed coherent heat containing Irminger Rings. The mooring deployment and recovery cruises were both on the R/V Knorr: KN192-01 in September 2007 and KN196-01 in September 2009, respectively. The single mooring held eight Aanderaa current meters (RCM-11), two Submerged Autonomous Launch Platforms (SALPs), and nine Seabird microcats (SBE37), deployed from 26 September 2007 through 27 September 2009, yeilding full water column (100-3000 meters) records of temperature, salinity, pressure, and velocity data for the two year period. The two SALP cages contained eleven APEX floats, and released some of these floats according to local oceanographic conditions, so as to seed the floats in passing Irminger Rings, and the remainder of floats as timed releases. Thirteen conductivity-temperature-depth (CTD) stations were taken on the mooring recovery cruise, creating a boundary current cross-section from the mooring site to Nuuk, Greenland.

17. Document Analysis a. Descriptors

Submerged Autonomous Launch Platform
Labrador Sea
mooring

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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